UNIT 14

RESPIRATION

Major Concept

14.1 Respiratory System of Man
14.2 Mechanism of Transport of Respiratory Gases
14.3 Respiratory Disorders

Learning Outcomes

Students will be able to:

- Define the respiratory surface and list its properties
- Describe the main structural features and functions of the components of human respiratory system
- Describe the ventilation mechanism in humans
- State lung volumes and capacities
- Explain how breathing is controlled
- Describe the transport of oxygen and carbon dioxide through blood
- Describe the role of respiratory pigments
- State the causes, symptoms and treatment of upper Respiratory Tract Infections (sinusitis, otitis media) and lower Respiratory Tract Infections (pneumonia, pulmonary tuberculosis)
- Describe the disorders of lungs (emphysema and lung cancer)
- List the effects of smoking on respiratory system

Introduction

For normal functioning of organisms chemical substances are needed, which must be transported into and around the body, while waste substances must be transported from where they are produced to outside.

Respiration is the one of most important processes in this respect. There are two levels of respiration *i.e.* external respiration and internal respiration.

External Respiration is also known as breathing which is the process of taking fresh air (containing more oxygen) into the respiratory organs (lungs) then to cells and removal of stale air (containing more CO_2) from respiratory surfaces or organs.

Internal Respiration is also known as cellular respiration. It is a catabolic process, releases energy from organic food molecules. The energy is released in the form of Adenosine Triphosphate (ATP) that is used for development, growth various bodily activities, repair damage parts and reproduction.

14.1 Respiratory System of Man

Respiratory system is responsible for the gaseous exchange between cells, body fluids (blood), respiratory surfaces and outer environment.

14.1.1 Properties of Respiratory Surfaces in Animals and Human

Respiratory surface are the areas where gaseous exchange between animals and environment occur. These surfaces in various animals are skin, tracheas, gills and lungs. The respiratory surfaces show following characteristics for readily exchange of gases through diffusion.

1. It should be large, moist and highly permeable for easy exchange of gases.
2. It should be thin epithelium (1mm or less) and also possess network of blood capillaries, which facilitate rapid transport and diffusion of gases between respiratory surface and blood.
3. A good ventilation mechanism should be present to maintain a steep diffusion gradient.

14.1.2 Components of Respiratory System of Man

This system can be divided into two main parts, the respiratory tract or air passage way and respiratory organs. The **respiratory tract** consists of external nostrils, nasal sacs or cavities, internal nares, pharynx, larynx, trachea, bronchi, bronchioles and alveolar ducts that terminate into the alveoli while respiratory organs are a pair of lungs.

14.1.3 Nose or Nasal Cavities

The human **nose** is the only externally visible parts of respiratory tract which is made of bones, cartilages and fatty muscle tissues. The external opening of nose is called

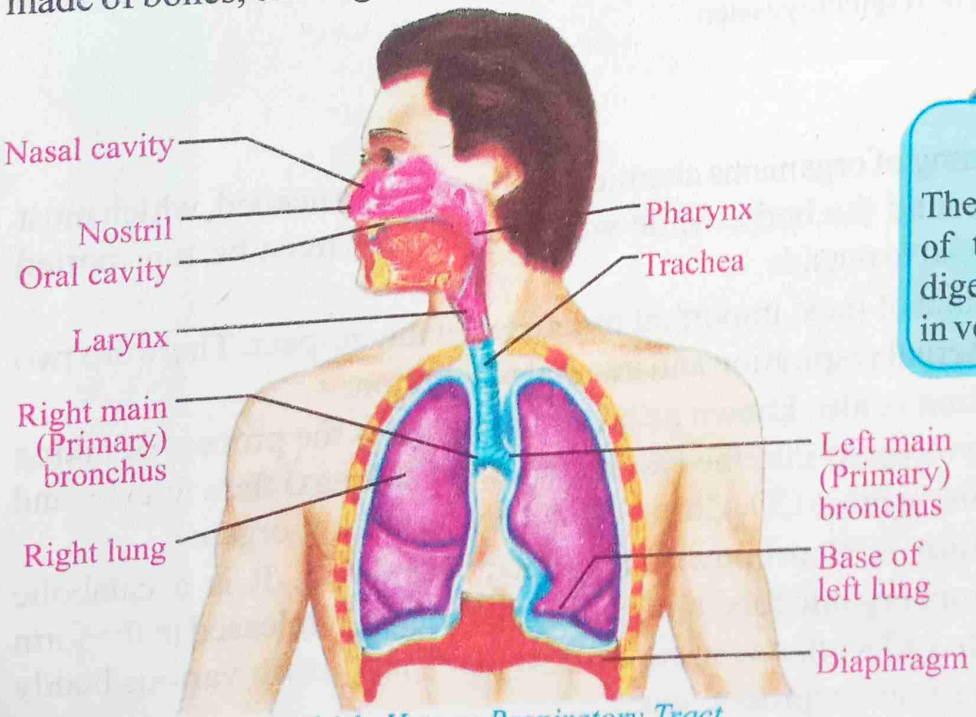


Fig. 14.1: Human Respiratory Tract

Extra Information

The throat or pharynx is part of the both respiratory and digestive system. It also helps in vocalization.

external nostrils. There is a nasal septum which separates two **nasal cavities** or **vestibules** from each other. These cavities contain a network of hair, lined by mucous membranes (secrete mucus) along with cilia, which serves as a defense mechanism against pathogens, trap dust and solid particulate substances present in the air. These substances are pushed to pharynx by cilia for removal.

The mucus also moists the air and brings the temperature of inhaled air close to body temperature about 30°C depending upon external temperature. (Fig.14.1)

14.1.4 Pharynx

The internal nostrils at the back of nose, opens the nose into the pharynx, which is muscular mucus secreting passage, cone shaped, conne-cts oral cavity and nasal cavities to the oesophagus and larynx. It consists of three sections, the **nasopharynx**, **oropharynx** and **laryngoph-arynx**. The inter connection of oral and pharyngeal cavity is medically beneficial to us, which allows to breath both by mouth and nose. (Fig.14.2)

14.1.5 Larynx

Larynx is also called **voice** or **sound box**. It is composed of cartilages and muscles, one of the cartilages that acts as a lid called **epiglottis**. During swallowing the epiglottis automatically covers the opening and cavity of larynx known as glottis. Two **vocal cords**, made of elastic fibres, placed horizontally in the lower side of glottis. The vibration of these cords produces voice. In adult male these cords are larger thus usually produce low pitched voices. (Fig. 14.3)

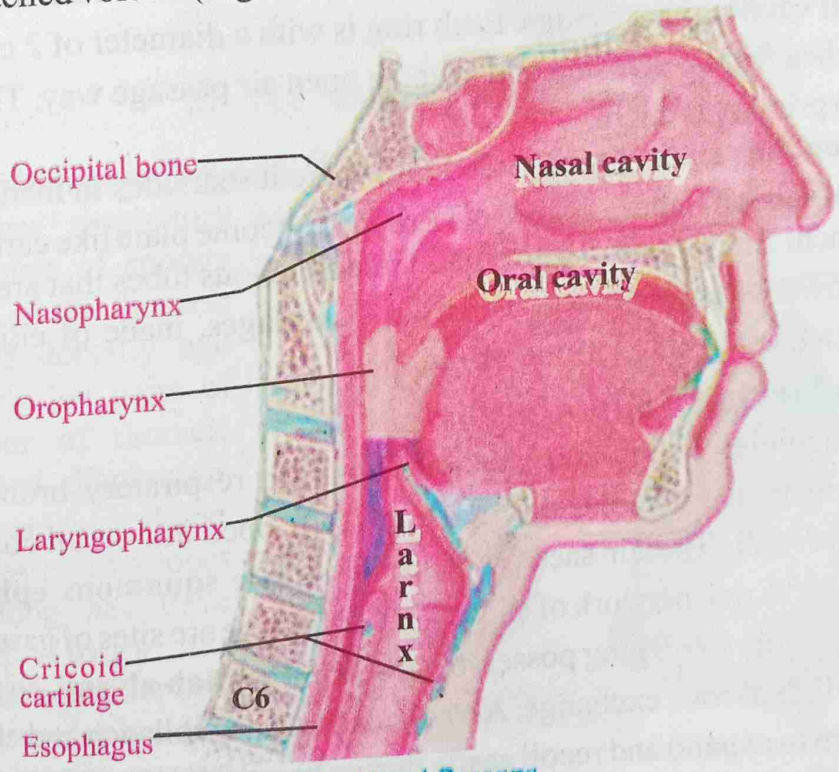


Fig. 14.2: Nasal Passage

There is a space between these membranes filled with fluid called **pleural fluid**. This fluid enables them to slide over one another and to prevent friction. (Fig. 14.5)

14.1.9 The Mechanism of Breathing (Ventilation)

The **breathing** is a mechanical process consisting of two phases *i.e.* inspiration or inhalation and expiration or exhalation. During **inspiration**, the fresh air containing more oxygen is pumped into the lungs while during **expiration** the air with more CO_2 is pumped out of the lungs. The lungs themselves neither draw in air nor push it out. The passive expansion of elastic lungs occur and also passive contraction of lungs occur during expiration. The complete expiration and contraction of the lungs is done by the combined action of **diaphragm, abdominal muscles** and **intercostal muscles** (muscles between the ribs).

During inspiration the space inside the chest is increased by two ways.

i) External rib muscles contract, which result in the upward and forward movement of the ribs, thus the pressure from the lungs is released and they expand.

ii) The muscles of diaphragm contract, lowering it and increasing the volume of the chest cavity.

Abdominal muscles relax to compensate for the compression of abdominal

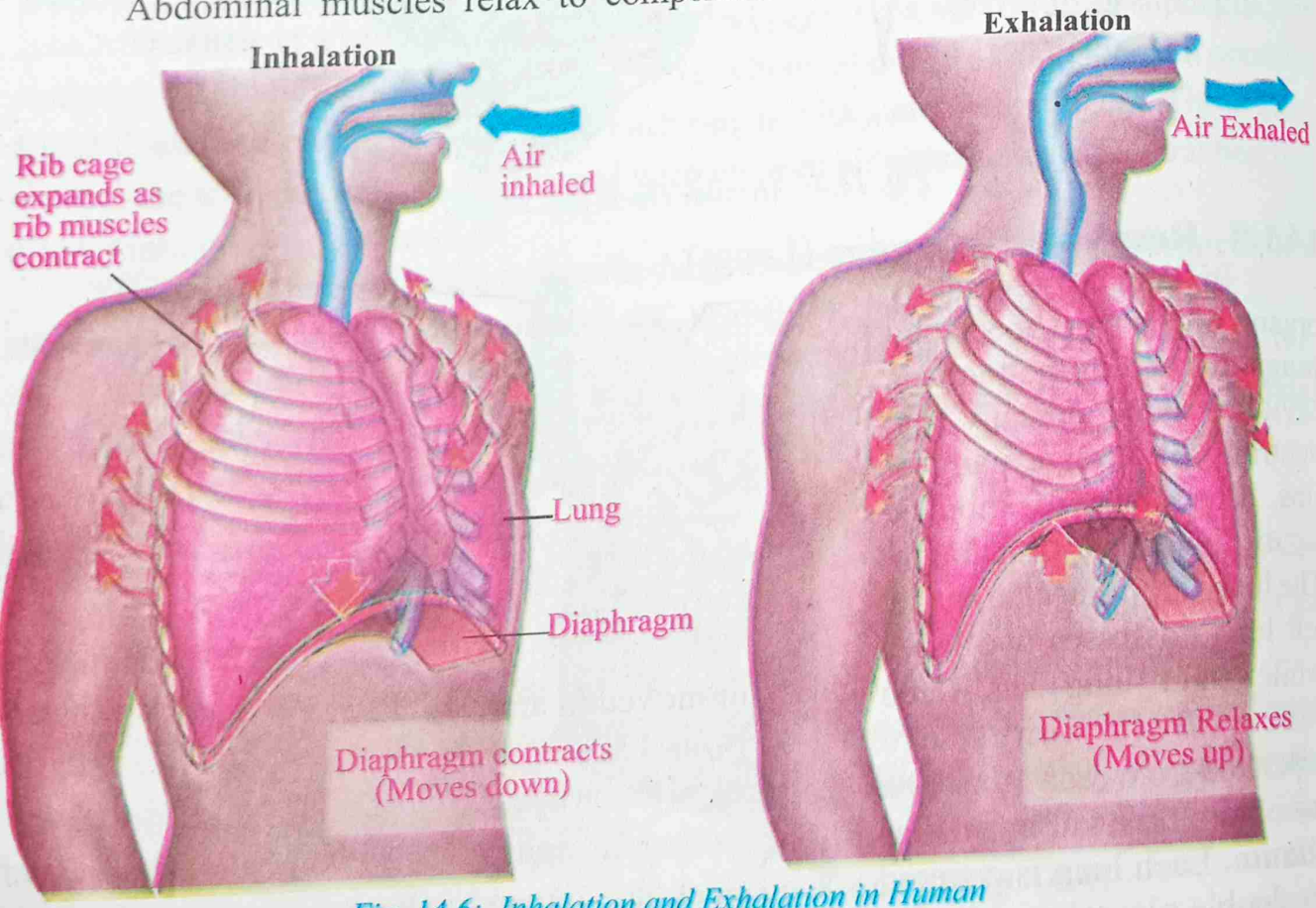


Fig. 14.6: Inhalation and Exhalation in Human

organs. The release of pressure from lungs by upward movement of ribs and increase in the chest cavity by downward movement of diaphragm causes the pressure in the chest cavity to drop below the atmospheric pressure and thus air rushes through the respiratory passage into the lungs to equalize the pressure inside and outside.

During expiration the volume of chest cavity is decreased. Muscles of the ribs are relaxed and the ribs move downward and inward, in this way from the side of the chest cavity the space becomes less.

At the same time the muscles of diaphragm also relax, the diaphragm projects into the thoracic cavity and become dome-shaped, therefore, the chest cavity is also reduced from the floor as well.

The abdominal muscles contract to push the abdominal organs against the diaphragm. The elastic lungs also contract and force the air to expel out. The reduction of space of the chest cavity exert pressure on the lungs thus the air inside the lungs move out of the lungs and this is known as expiration. (Fig. 14.6)

Table: 14.1 Differences between internal and external respiration

S.No.	External Respiration	Internal Respiration
i)	It is the exchange of respiratory gases (O_2 and CO_2) between the organism and its environment.	It is a biochemical process occurs within the cell to oxidize food molecules.
ii)	It is exchange of gases between circulatory fluid and external environment.	It is exchange of gases between the cell and circulatory fluid.
iii)	No ATP, H_2O are formed.	ATP, CO_2 and H_2O are produced.
iv)	It is aerobic respiration.	It may be aerobic or anaerobic respiration.

14.1.10 Lungs Respiratory Volumes and Capacities

The **respiratory volume** is also known as **pulmonary volume**, which is the amount of air inspired, expired and stored within lungs at any given time. It is the amount of air during breathing.

Tidal volume is the amount of air moved in and out with each quiet breath which is normally 500 ml during deep breath. We can increase the inspiration by as much as 3000 to 4000 ml of air during forced inspiration. This is known as **inspiratory reserve** volume. About 1200 – 1500 ml air always remains in the lungs (even during deep breath), this is called **residual volume**. (Fig. 14.7)

Extra Information

Spirometer is a device which helps to measure the respiratory volume and the process.

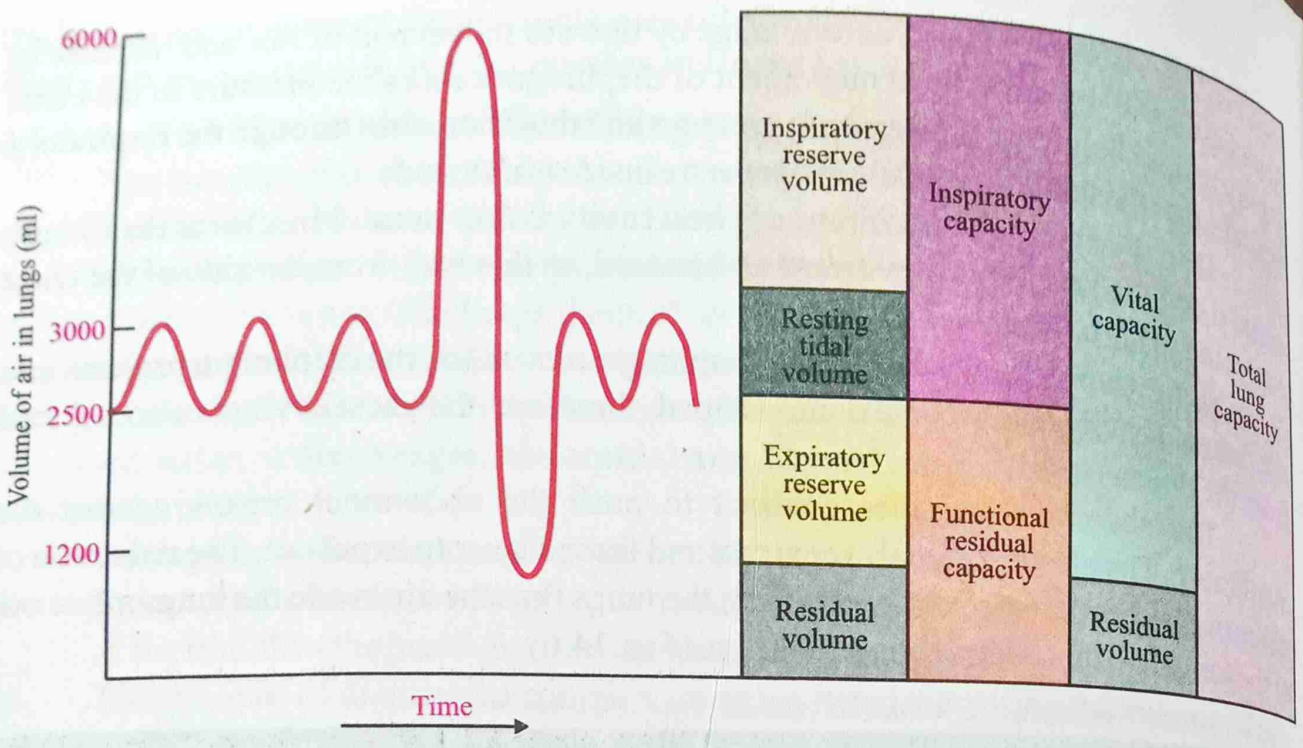


Fig. 14.7: Respiratory Volume

14.1.11 Controlling Centres of Breathing

Breathing is controlled both involuntarily and voluntarily. The **medulla** of our brain is controlling centre for involuntary breathing. The normal breathing rate is 15–20 times per minute. The voluntary or consciously control centre is **cerebral cortex of cerebrum** while **limbic system** of the brain also acts as respiratory centre during emotional acts.

Extra Information

The lower portion of medulla acts as inspiratory centre while upper and lateral portions acts as expiratory centres.

14.2 Mechanism of Transport of Respiratory Gases

Respiratory gases **(CO_2 and O_2)** are transported to various body regions by means of blood.

14.2.1 Respiratory Pigments and their Role

i) Haemoglobin is the most important respiratory pigment present in many animals including man. It is a complex protein consisting of four polypeptide chains *i.e.* 2 alpha chains and 2-beta chains having 574 amino acids. Each chain is associated with an haeme group. Haeme group is an iron containing group, which consists of **porphin** with a central atom of ferrous (iron) between four pyrrole rings. (Fig. 14.8)

Function of Haemoglobin

Haemoglobin is an iron containing protein in the red blood cells of vertebrates. It

transport oxygen to the tissues. Haemoglobin increases the oxygen carrying capacity of the blood in human to about 75 times. Iron in haemoglobin combines loosely with oxygen in the red blood cells (RBC) of pulmonary capillaries to form oxyhaemoglobin. This bright red blood containing oxyhaemoglobin is then circulates and reaches tissue and cells of the body where oxyhaemoglobin releases oxygen. This happens because haemoglobin has a property to release its oxygen where there is low concentration of oxygen and color of blood become purple red. After releasing oxygen, the haemoglobin returns back to the lungs with deoxygenated blood, to become again oxyhaemoglobin.

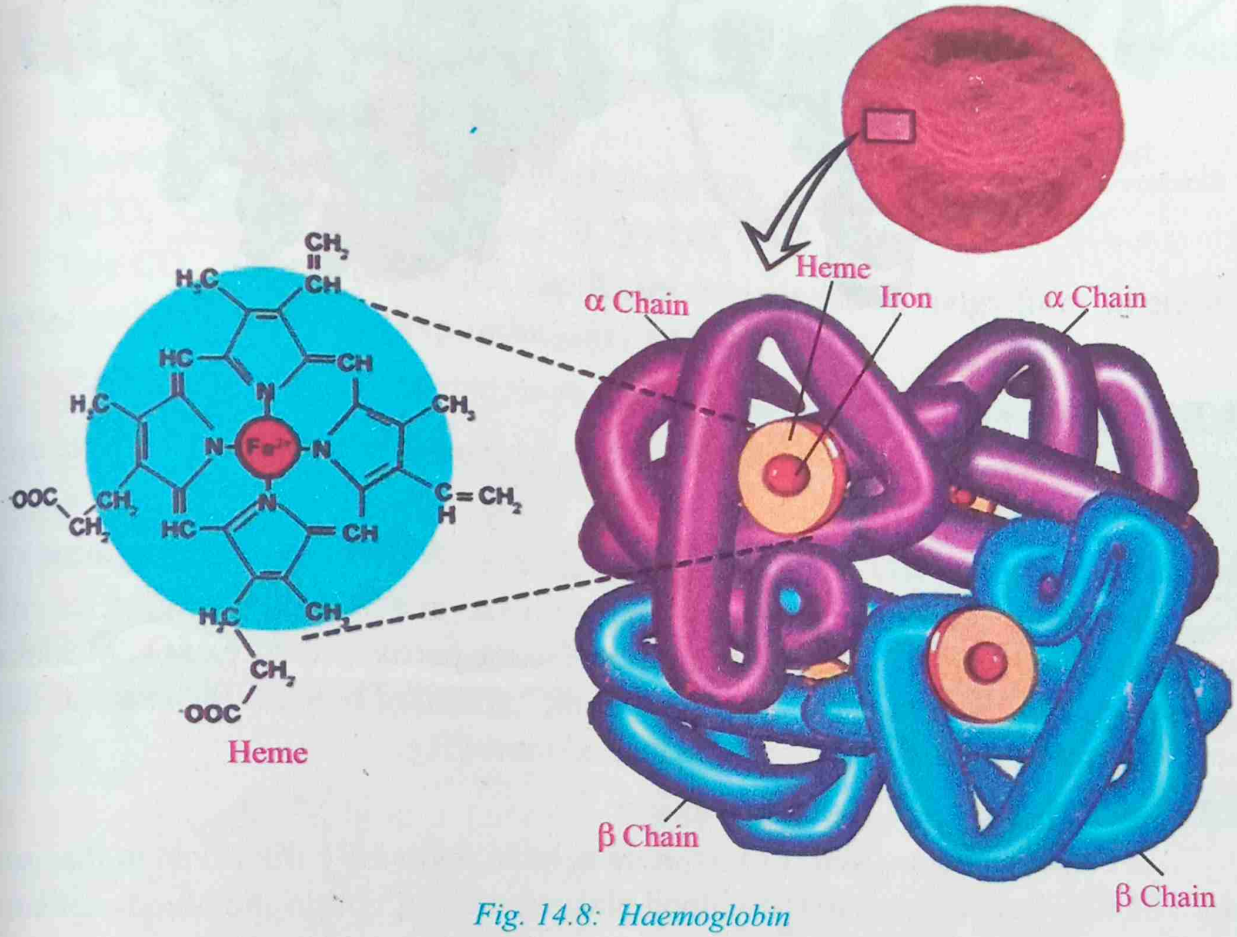


Fig. 14.8: Haemoglobin

ii) **Myoglobin** is another respiratory pigment in man, which is present in the muscle of human and other mammals. Therefore, meat is red. It is made of one iron containing polypeptide chain (contain 154 amino acids and bind only one molecule of oxygen).

Function of Myoglobin:- It stores oxygen in the muscle and gives oxygen when partial pressure of oxygen is below 20 mm of Hg. It has more affinity to combine with oxygen than haemoglobin. (Fig. 14.9)

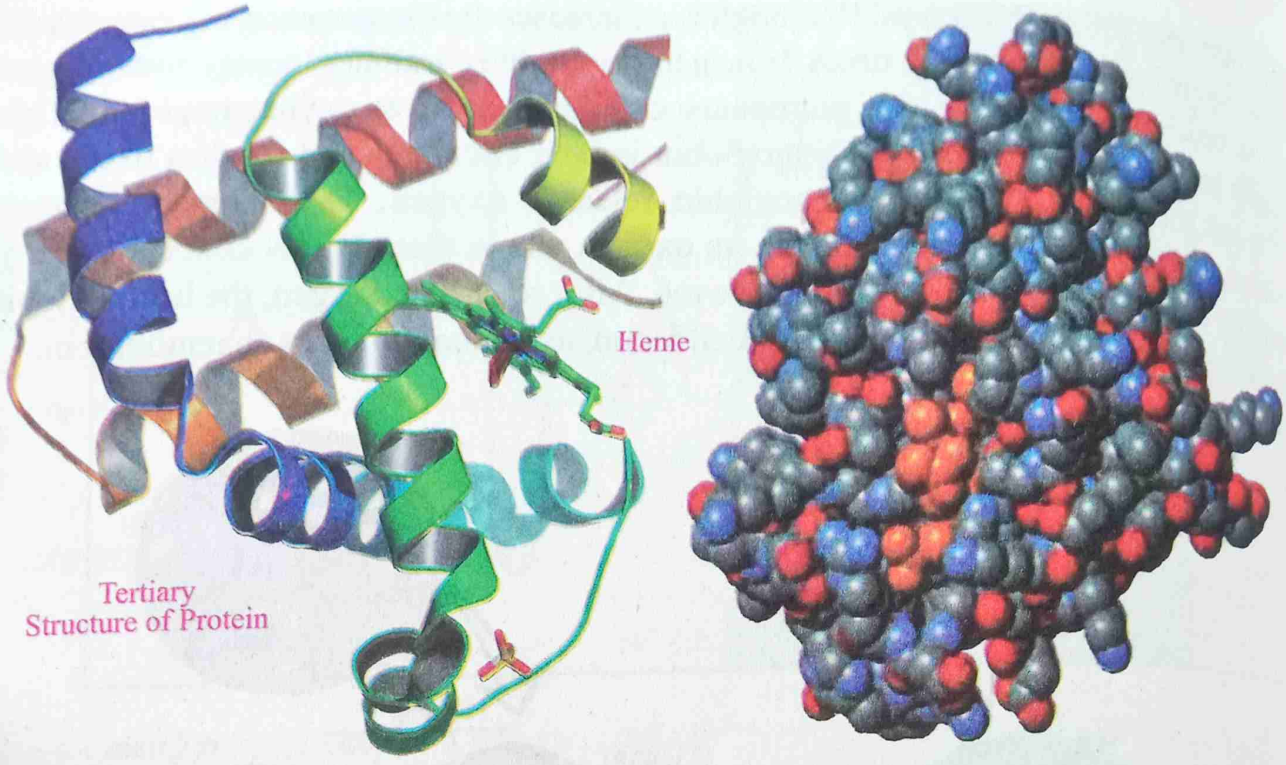


Fig. 14.9: Myoglobin

14.2.2 Transport of Oxygen in Blood

About 97-98% oxygen is carried by haemoglobin while remaining 2-3% transport as dissolved oxygen in plasma.

$$\text{Hb (Haemoglobin)} + 4O_2 \underset{}{\overset{\text{Carbonicanhydrase}}{\rightleftharpoons}} 4O_2\text{Hb (oxyhaemoglobin)}$$

The ability of haemoglobin to bind with oxygen is called oxygen carrying capacity of blood, which is directly proportional to the partial pressure of O_2. Maximum O_2 carrying capacity of blood at sea level is 20ml / 100ml of blood (100% saturated). It loses oxygen when partial pressure is less than 60 mm of Hg.

14.2.3 Transport of Carbon Dioxide

As compared to oxygen, CO_2 is more soluble and easily dissolved in the tissue fluid. The CO_2 from tissue passes to blood plasma, present within the blood capillaries where its transport occurs by three ways.

i) As bicarbonate ions (about 70%).
ii) As carboxyhaemoglobin (about 23%)
iii) As dissolved CO_2 in plasma (about 7%)

i) As bicarbonate ions (HCO_3)

First of all, the CO_2 is released as a result of oxidation reduction reaction and enters the plasma of the blood in tissue fluid. In blood, CO_2 combines in the presence of

an enzyme named as carbonic anhydrase with water inside RBCs and form carbonic acid.

$$CO_2 + H_2O \xrightarrow{\text{CarbonicAnhydrase}} H_2CO_3 \text{ (Carbonic Acid)}$$

The carbonic acid splits quickly and ionizes to form hydrogen ions (H^+) and bicarbonate ions (HCO_3).

$$H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$$

All these reactions are reversible. When the blood leaves the capillaries and comes into blood vessel all the CO_2 is now in the form of bicarbonates. Bicarbonates diffuse out of the red blood cells and carried by the plasma and H^+ is absorbed by the globin protein of haemoglobin.

When the blood reaches the alveoli of lungs capillaries, the bicarbonate ions again combine with H^+ ions to form carbonic acid again.

$$HCO_3^- + H^+ \rightleftharpoons H_2CO_3$$

The carbonic acid again splits into H_2O and CO_2

$$H_2CO_3 \xrightarrow{\text{CarbonicAnhydrase}} H_2O + CO_2$$

This CO_2 diffuses out of the capillaries into alveoli of lungs from where it is expelled out by the process of expiration. (Fig.14.10)

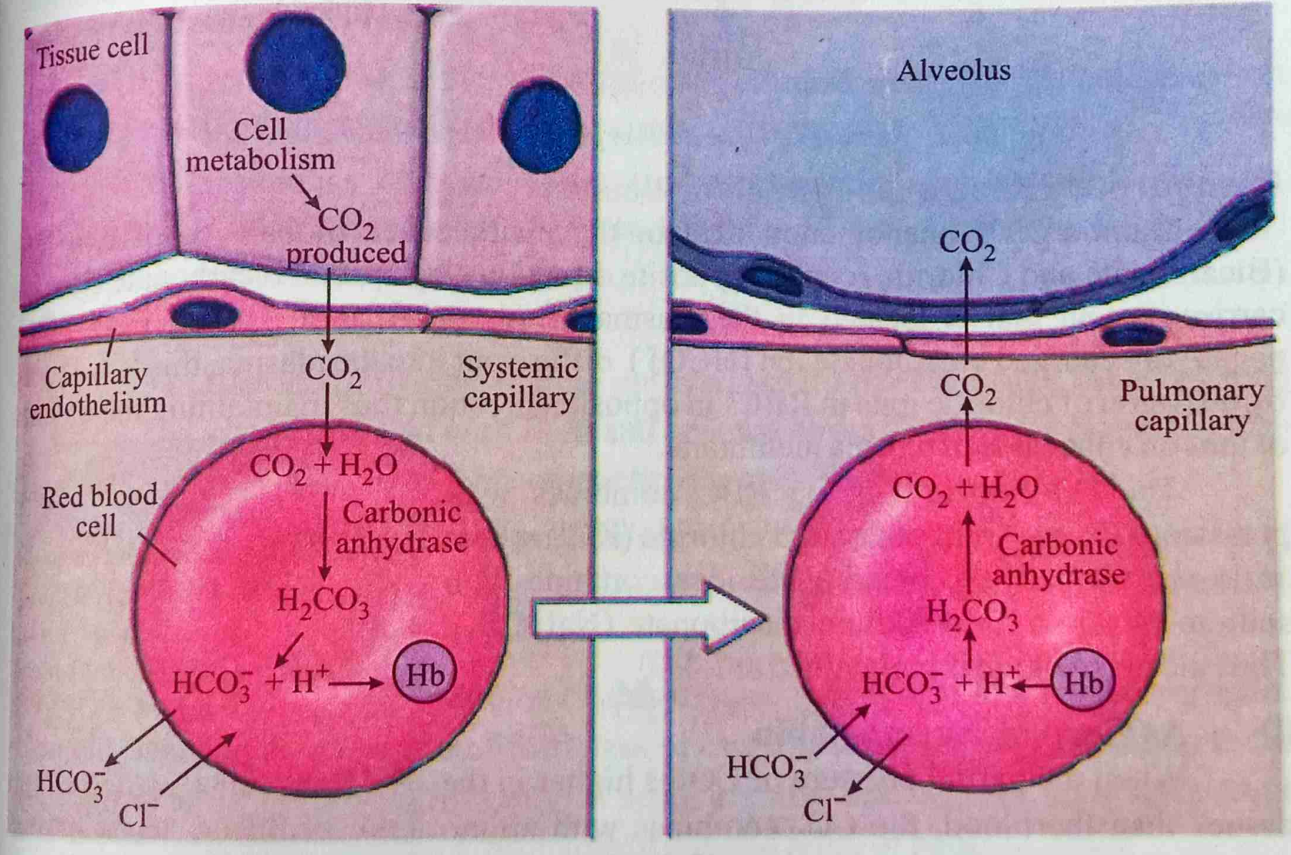


Fig. 14.10: Transport of CO_2 (From Cells to Alveolus)

Role of Hydrogen Ions

The pH of blood may decreases due to H^+ ions in the blood, but it does not occur since haemoglobin acts as buffer for Hydrogen ions. The oxyhaemoglobin readily combines with hydrogen ions to become reduced into **haemoglobin acid (HHb)** and oxygen is released to the tissues. (Fig.14.11)

$$4O_2\ Hb + H^+ \square\square\square \quad HHb + 4O_2$$

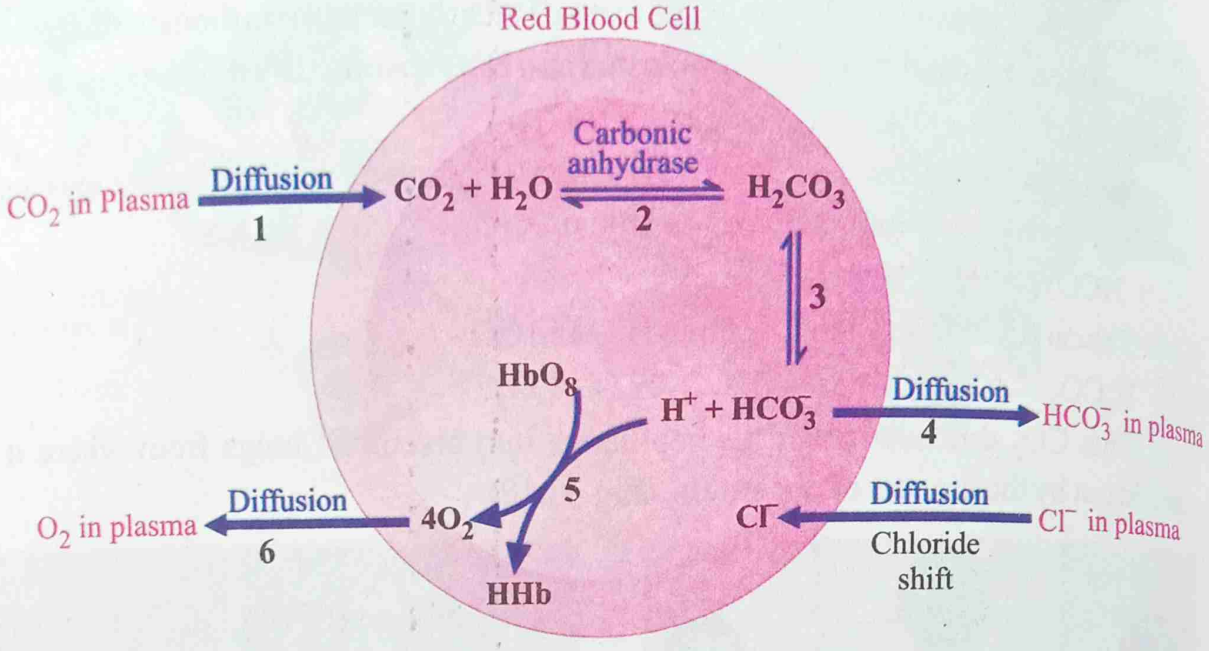


Fig. 14.11: Release of O_2 and Absorption in Blood Plasma and RBC

Hamburger`s Phenomenon or chloride shift

Hamburger`s phenomenon explain the maintenance of balance of two ions (Bicarbonate and Chloride Ions) in opposite directions, by special bicarbonate chloride carrier protein that is located in the plasma membrane of RBC. When from RBCs negatively charged bicarbonate ion (HCO_3^-) diffuse out into the plasma, this is balanced by diffusion of chloride ions in RBCs in opposite direction thus maintaining the balance of ions on either side of plasma membrane.

The chloride ion in the RBC combines with potassium (K^+) to form potassium chloride (KCl) where as in the plasma, the bicarbonate ions combine with sodium (Na^+) to form sodium bicarbonate ($NaHCO_3$). Thus the pH of blood is maintained at 7.4.

ii) As Carboxyhaemoglobin

When the partial pressure of CO_2 is higher in the tissues than the blood, the CO_2 combines with amino group of haemoglobin to form carboxyhaemoglobin. In

Extra Information

The CO_2 concentration. in arterial blood is 50ml / 100 ml of blood while venous blood contains 54 ml /100 ml blood, thus only 4 ml of CO_2 as it passes through the tissue-es and gives off 4 ml of CO_2 /100 ml of blood as it passes through the lungs.

the lungs the partial pressure of CO_2 is less than blood, it again breaks and releases CO_2.

iii) As Plasma Protein

Some CO_2 (about 7%) transported from tissue fluids to the lungs with the help of plasma proteins, which is rather inefficient way to carry CO_2.

14.3 Respiratory Disorders

Many problems in respiratory system can take place if inner lining of respiratory organs exposed continuously to unhealthy air, containing poisonous gases. (Such as smoke and other pollutants). Some common respiratory disorders are as under.

14.3.1 Upper Respiratory Tract Infections

i) Sinusitis

The **sinuses** are holes in the skull between the facial bones and inflammation in these holes is called sinusitis. So the **sinusitis** may be **acute** (if symptoms last 2-8 weeks) or **chronic** (slowly progress and symptoms last much longer).

The sinuses are lined with mucus secreting membrane, which secretes antibody rich mucus, helps to trap and prevent entry of irritants.

Interesting Information

There are four large sinuses, two maxillary lie inside the cheek bones and two frontal sinuses, lies above the eyes.

Causes: It is generally caused by atmospheric pollution, dust, smoke, cold and wet climate, excessive dryness and bacterial or viral infections, etc.

Treatment: Antibiotics or sulfa drugs are recommended for bacterial infection. Antiallergic and decongestants are also prescribed by doctors. Steam inhalation called **nebulization** is also useful to treat sinusitis.

ii) Otitis Media

It is an inflammation of the middle ear in which **Eustachian tube** (tube between middle ear and pharynx) filled with fluid and become close. If this fluid is not clear up after three months or more, then it becomes **chronic otitis media**.

Causes: The main causes of otitis media are infection, allergy, recurrent attacks of common cold, blockage of Eustachian tube, nutritional deficiency and sinusitis, measles, etc.

Symptoms: The common symptoms of this disease are sudden and severe ear ache, deafness, fever, headache, sense of fulfilness of ear, **tinnitus** (ringing or buzzing in the ear), fluid leaking from ear, difficulty in speaking and hearing, etc. Sometime even eardrum can burst, which causes a discharge of pus and relief of pain.

Treatment: Mostly (around 80% patients) treated by clearing up the fluid within three to four days, **ear drum** has self-repairing ability. However, for complicated cases antibiotic therapy is prescribed. Pain killers may be given to relieve pain and fever.

14.3.2 Lower Respiratory Tract Infections

i) Pneumonia

It is serious disorder of lower respiratory tract. Pneumonia is characterized by inflammation of alveolar wall and accumulation of fluid and pus in alveolar sacs of one or both lungs. (Fig.14.12)

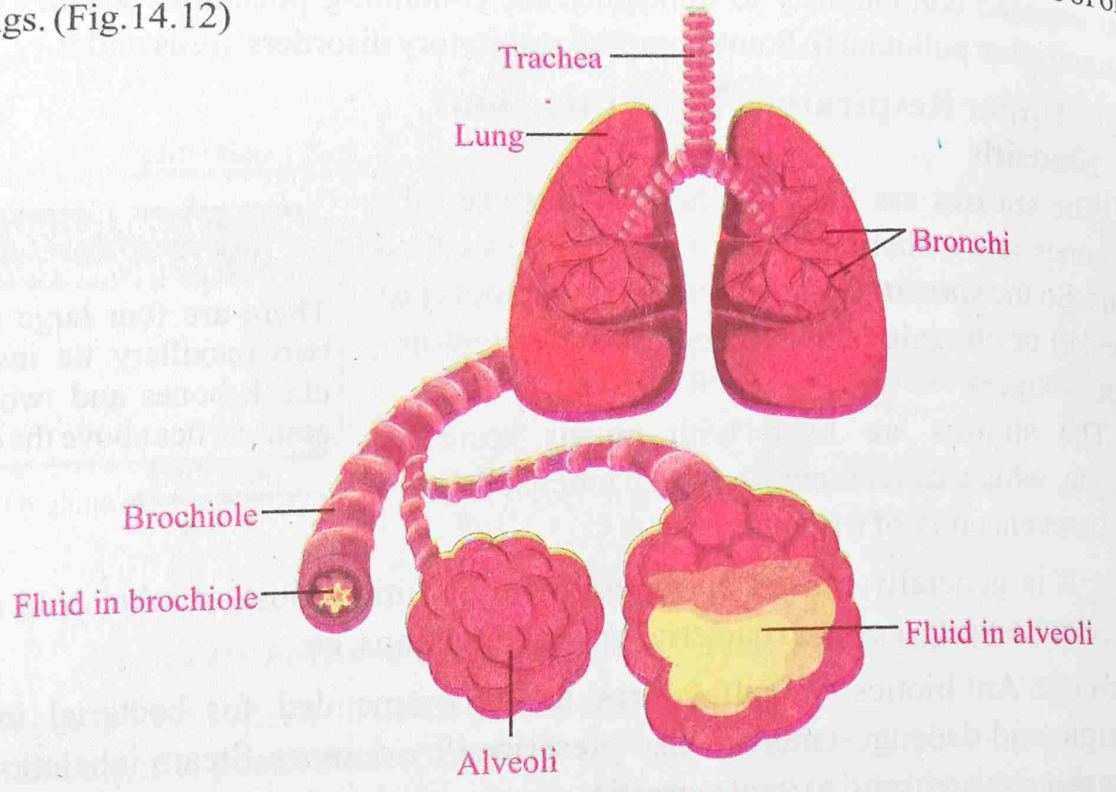


Fig. 14.12: Pneumonia of the Lungs

Causes: Mostly caused by bacterial genera such as ***Streptococcus pneumoniae, Staphylococcus aurexs, Haemophilus influenza and Mycoplasma,*** etc. Sometime it also occurs due to viral, fungal or protozoan infection.

Symptoms: The person with bacterial pneumonia may experience with chill, chattering teeth, shaking, chest pain, sweating due to high fever, increase pulse rate and breathing, violent coughing (due to *Mycoplasma*). In viral and other form dry cough, headache, fever and muscle pain, bluish color of lips, and red brown rusty color sputum are also symptoms of pneumonia.

Treatment: Mostly antibiotic treatment is prescribed.

ii) Lung Cancer

Cancer is **malignant tumor** which may develop due to uncontrolled cell division.

It is one of the most common cancer in the world.

Causes: Smoking and inhalation of unhealthy air. The chances of lung cancer are ten times more in those persons who smoke or live in crowded smoky areas. It is estimated that 90% of lung cancer is caused by smoking. (Fig.14.13)

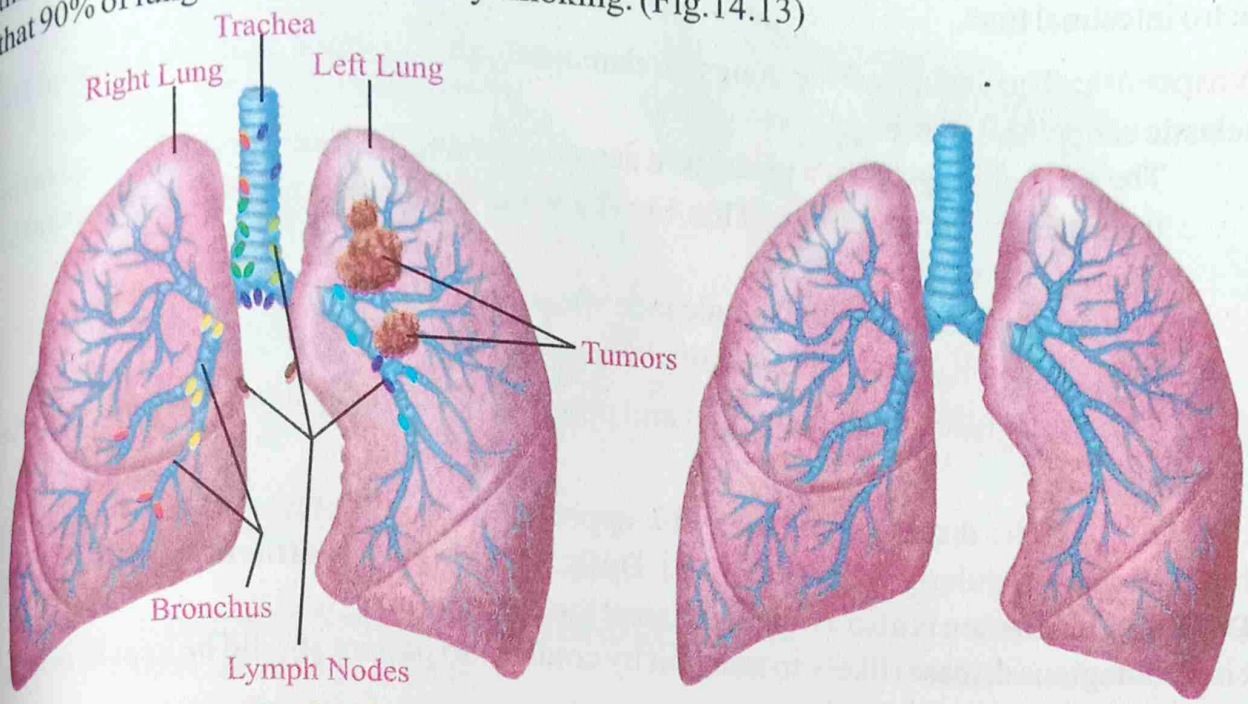


Fig.14.13: Lung Cancer (Cancerous and Healthy Lungs)

Symptoms: In initial stages the thickening and **callusing** (hardening) of cells occur, which are present in the lining of bronchi. The cilia in nasal passage (to prevent dust and dirt from seating in the lungs) are destroyed. The tumor consisting of disordered cells, spread and penetrates to other tissues known as **metastases**. These tumors grow until the bronchus is blocked and cutting off the supply of air to lung. The secretions are trapped in the spaces of lungs and become infected known as pneumonia or a lung abscess (swelling area containing pus) or only lung abscess result.

Extra Information

Pneumonectomy: Surgical removal of lung or part of lung.

Chemotheraphy: The use of chemical agents to treat or control diseases.

Radiotherapy: A therapy (Treatment) using ionizing radiation, generaly as a part of cancer treatment to control or kill malignant cell.

Treatment: To remove the tumor or the lung completely before the secondary growth has to occur. This operation is called **pneumonectomy**. **Chemotherapy** and **radiotherapy** may treat cancer.

iii) **Pulmonary Tuberculosis (TB)**

It is infectious bacterial disease of lower respiratory system. It is more common in

poor people due to poor living conditions and malnutrition.

Causes: Pulmonary tuberculosis is caused by a *Bacillus* bacterium known as ***Mycobacterium tubercle.*** Although about 15% develop TB of lymph nodes, joints and gastro intestinal tract.

Symptoms: The inside of the lungs is damaged, alveoli burst and are replaced by inelastic connective tissue.

- The cells of lungs form a protective capsule around the bacteria and isolated them from the rest of the body. This tiny capsule is called tubercle (small rounded swelling).
- The patient has cough, fever, pale face and sweating at night.
- In severe form, chest pain and breathlessness may occur.

Facilitating Condition: Malnutrition and poor living conditions facilitate the bacteria to grow.

Treatment: The disease is curable with appropriate drug therapy such as antibodies (for 9 months regularly). This is called **Daily Observed Treatment Short Course (DOTS)**. Vaccination is also available against the bacteria.
It is a contagious disease (likely to transmit by contact) so patient should be kept in isolate environment to prevent infection.

iv) Emphysema

It is a lung disorder in which the air sacs (alveoli) degenerate and the elastic fibers present in them are destroyed. As a result, alveolar wall degenerate and small alveoli combine to form larger alveoli. This results in less alveoli with an increased volume and decrease surface area for complete gaseous exchange.

Symptoms: Increasing breathlessness, patient faces difficulty in walking. Lung loses elasticity, so it becomes more difficult to exhale air and lot of air remains in the lung during expiration. Inflammation and narrowing of bronchioles occur. The patient feel fatigue, coughing and **cyanosis** (blue skin). (Fig. 14.14)

Causes: The root cause of emphysema is the long term irritation of the lungs by cigarette smoke, polluted air or industrial dust and exposure of lungs to certain drugs, coal, etc. The substances present in the smoke of tobacco weakens the walls of alveoli.

Treatment: There is no cure of emphysema but some care may be helpful.

- Avoid smoking.
- All kinds of respiratory infections should be treated immediately.
- Oxygen equipment and respiratory devices are helpful.

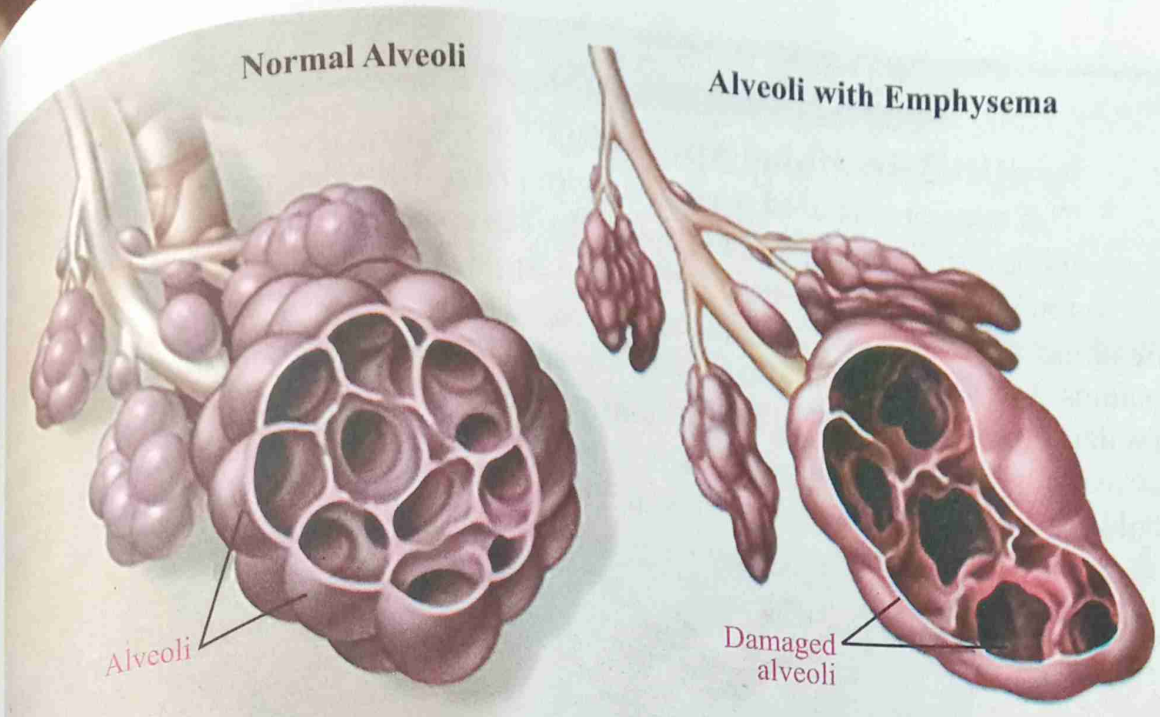
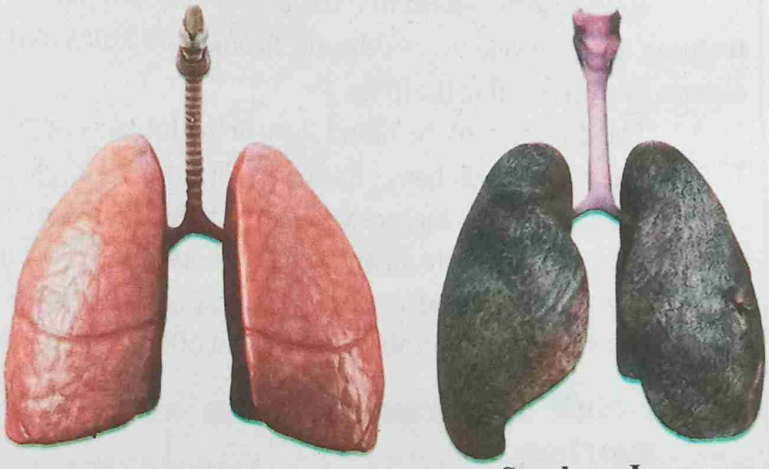


Fig. 14.14: Alveoli (Normal and Emphysema)

14.3.3 Effects of Smoking on Human Health

There are many effects of smoking on our respiratory system such as 87% of cigarette smokers also develop lung cancer. The smoking causes cancer of mouth, larynx and oesophagus. Smoking also causes many other diseases such as chronic bronchitis and emphysema.

The smoke of cigarette contains chemicals which irritate the respiratory tract and lung which results in early morning coughing and wheezing. It is indirect cause of pneumonia because cigarette smoke damages or destroys cilia. Thus microbes cannot be trapped and are easily settled in respiratory system. (Fig.14.15)



Healthy Lungs
In healthy people, the lungs are light pink

Smokers Lungs
In smokers, the lungs appear dark and mottled

Fig.14.15: Effects of Smoking

- **Artificial Breathing Apparatus**

This apparatus is used when we swim under the water and the areas with low oxygen concentration such as at high altitude. The apparatus is also used by fire fighter. It is commonly called **aqua-lung** or **SCUBA apparatus** (Self Contained Under Water Breathing Apparatus). It contains compressed air that is a mixture called **nitrox**, contains about 35% oxygen and 65% Nitrogen. The pressure of compressed air is much less than ambient pressure (The **ambient pressure** on an object is the pressure of the surrounding medium, such as a gas or liquid, in contact with the object), thus divers could breathe readily at any depth of water or areas with low oxygen.

- **Respiratory system in birds is the most efficient and elaborate. Why?**

Respiratory system in birds is the most efficient than other animals due the following features. There is one way of the air through the lungs and air is renewed after inspiration and also no foul air is left in the lungs.

The direction of the blood flow in the lungs is opposite to the air flow, the parabronchi. This counter current exchange increases the amount of oxygen which enters the blood.

Also birds have air sacs which reach into all parts of the body and even penetrates some bones. These air sacs store air and act as balloons and blow air into parabronchi for exchange of gases. This system provides a large amount of oxygen for the high metabolic rate, and birds can breathe and fly on high altitude of about 6000 meter or more.

- **Relate the transportation of gases to hiccups, sneezing and snoring.**

The hiccups, sneezing and snoring are the conditions which are related to breathing.

Hiccups:- It is sharp respiratory sound produced by the spasmodic contraction of the diaphragm while the glottis is closed. It is reflexive and serve no known functions but person feels difficulty in breathing.

Sneezing:- Deep inspiration followed by a closure of the glottis. The forceful expiration that results abruptly opens the glottis, sending a blast air through the nasal cavity. The eyelids close

EXERCISE

SECTION-I: OBJECTIVE QUESTIONS

Multiple Choice Questions (MCQs)

A. Select the correct answer.

1. Pleura is a double layered thin membrane that covers:
   (a) Heart (b) Liver
   (c) Kidney (d) Lungs

2. Hemoglobin in man increases the oxygen carrying capacity of the blood to about:
   (a) 75 times (b) 50 times
   (c) 60 times (d) 100 times

3. Plasma proteins are involved in the release of CO_2.
   (a) 70% (b) 7%
   (c) 30% (d) 20%

4. Structure, which closes the passage to lungs when food is coming, is called:
   (a) Glottis (b) Epiglottis
   (c) Uvula (d) Pharynx

5. Myoglobin loses oxygen at:
   (a) 60 mm Hg (b) 19.6 mm Hg
   (c) 90 mm Hg (d) 20 mm Hg

6. Breathing is an example of:
   (a) Diffusion (b) Osmosis
   (c) Ventilation (d) Cellular Respiration

7. The structure which prevents entry of food to wind pipe is called:
   (a) Glottis (b) Epiglottis
   (c) Tongue (d) Soft palate

8. Which one of the following lacks cartilage?
   (a) Trachea (b) Bronchioles
   (c) Bronchi (d) Larynx

9. The pleural fluid surround the:
   (a) Liver (b) Kidneys
   (c) Heart (d) Lungs

10. The percentage of CO_2 carried in the form of bicarbonate is:
    (a) 85% (b) 60%
    (c) 70% (d) 65%

11. Each molecule of myoglobin combines with one molecule of:
(a) Oxygen (b) Carbon dioxide
(c) Nitrogen (d) Sulphur

12. In human, respiratory pigment is:
(a) Haemocyanin (b) Haemoerythrin
(c) Chlorocrurin (d) Haemoglobin

13. The residual volume of air in human lung is
(a) 2.5 liter (b) 5.0 liter
(c) 1.5 liter (d) 3.0 liter

14. Chemotherapy and radiotherapy may help in the treatment of:
(a) Flu (b) Emphysema
(c) Lung cancer (d) Asthma

15. *Mycobacterium tubercle* causes:
(a) Emphysema (b) Sinusitis
(c) Pneumonia (d) Pulmonary tuberculosis

B. Fill in the blanks.

1. Respiratory surface must be permeable, so that ..... can pass through it.
2. The pharynx is part of both the respiratory and ..... system.
3. The trachea divides into two primary .....
4. Each lung contains about 35 millions .....
5. About 97- 98 % of O_2 is carried by the RBC as .....
6. The chloride shift is also called ..... phenomenon.
7. Sinusitis is an inflammation of nasal .....
8. Haemoglobin can carry ..... oxygen.
9. ..... media is an inflammation of middle ear.
10. Mycoplasma cause lower respiratory infection named .....

16.1 Human Skeleton

Human's skeleton is the main supportive framework of the body. It mainly includes bones and cartilages. The muscles are attached to the skeleton for the production of effective movements of the body.

Skeletal tissues:- Skeletal tissues are bone or cartilage

Bone:- Bone is one-third of connective tissue. It is impregnated with calcium salts. The composition of bone tissue is different from other tissues in the body. Bone is a hard tissue, provides support to the body, gives environment for the production of blood cells and protects internal organs of the body.

16.1.1 Structure of Bone

Bone tissues are of two types; **compact** (hard and dense) and **cancellous** (spongy) tissues. The outer part of bone is hard, called compact bone while the inner part is spongy, called spongy bone.

Compact bone

Compact bone, also called **cortical bone**, is a hard white bone tissue that surrounds all the bones in human body. The fundamental units of compact bone are called **osteons** or **Haversian systems.** Each osteon consists of concentric layers called **lamellae** (singular: lamella). In the centre of each osteon, **central canal** or **Haversian canal** is present which contains blood and nerve supply of the bone. The central canal communicates with the **perforating canal** (also called **Volkmann's canal**), which transmits blood vessels from periosteum (a dense layer of vascular connective tissue enveloping the bone) into the endosteum (The thin layer of cells lining the medullary cavity of a bone).

The **osteocytes** are located in the small cavity called **lacunae** (singular: lacuna), situated between the lamellae. **Canaliculi** are the microscopic channels that create a network which transport nutrients, to the osteocytes and also remove wastes from them.

Spongy bone

Spongy bone, also called cancellous or **trabecular bone**, is a porous and highly vascular bone. It is mostly located at the end of the long bones. Unlike compact bone, the lacunae of spongy bone are found in a lattice-like network of matrix spikes called **trabeculae** (singular: trabecula). The **osteocytes** of spongy bone are irregularly placed within the trabeculae. The spaces between trabeculated networks make spongy bone lighter and less dense than compact bone. The spaces in some spongy bones contain **red bone marrow**, where the blood cells are formed. (Fig.16.1)

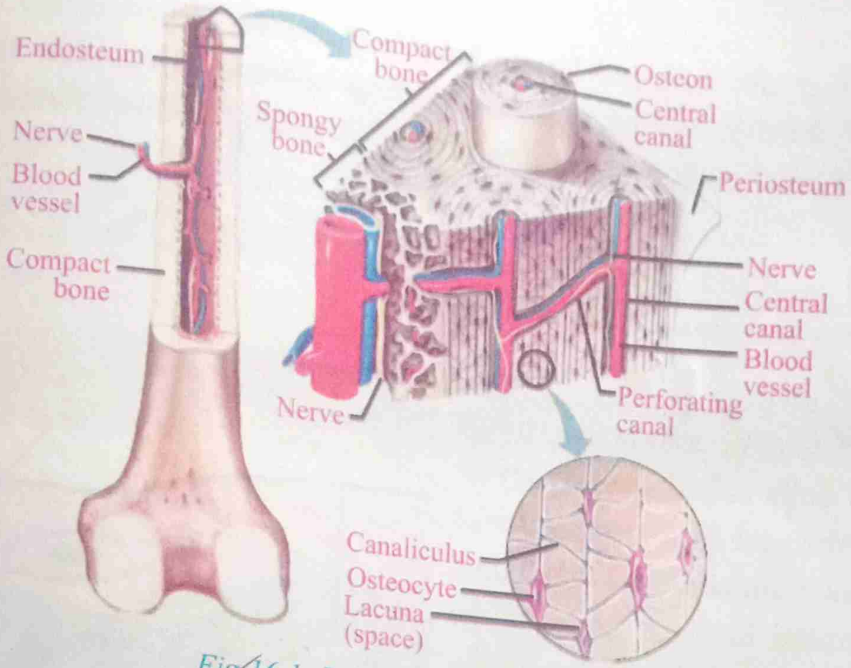


Fig.16.1: Internal Structure of Bone

Types of Bone Cells

The process of bone growth and repair is carried out by four different types of cells. These cells are involved in making and breaking the bone.

1. **Osteogenic Cells** are the stem cells that are found in the cellular layer of endosteum and periosteum. These are undifferentiated cells and have ability to divide. The osteogenic cells develop into osteoblasts.

2. **Osteoblasts** are involved in the formation of new bone. They are mostly found in the areas where bone growth occurs. These cells secrete collagen.

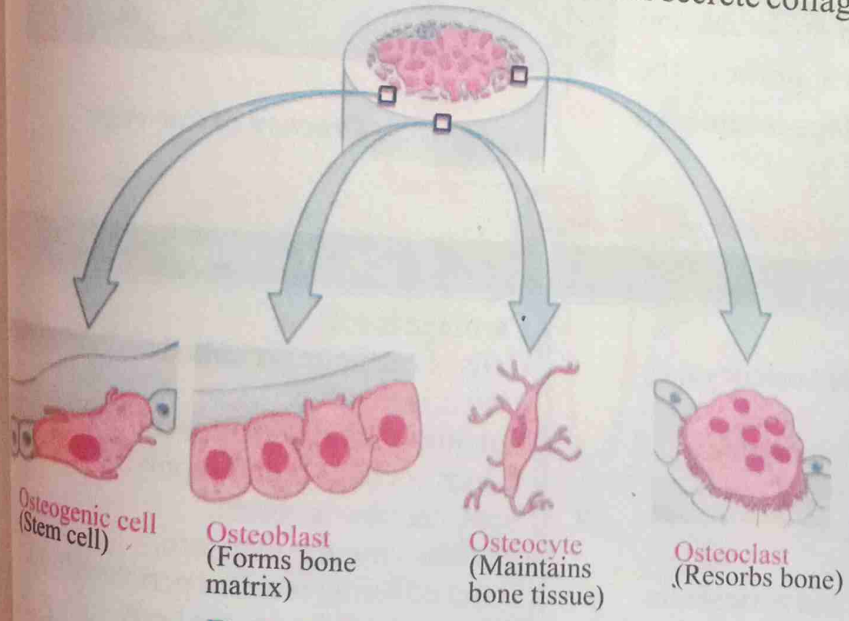


Fig.16.2: Types of Bone Cells

Extra Information

A new "inner you" is about ten years old. In adult human every year about 10% bone is replaced, that means as the mineral content in bones is renewed, we get a new skeleton about every ten years.

3. **Osteocytes** are matured bones cells and are entrapped in the matrix. When osteoblasts are surrounded by the matrix, they become osteocytes. By the help of secretion of enzymes, osteocytes maintain mineral concentration of the matrix.

4. **Osteoclasts** take part in bone resorption and breakdown processes. These cells are found at the sites of old, injured bone. Osteoclasts are multinucleated and are derived from **monocytes and macrophages**. (Fig.16.2)

16.1.2 Cartilage

Cartilage is a connective tissue compos-ed of cells called **chondrocytes** and fibers embed-ed in a firm, gel like matrix. It is much more elastic than bone. Cartilage is found in many areas of the body including joints, between the bones, *e.g.* the elbow, knees and ankles.

The general features of cartilage include that it has no blood vessels or lymphatics. The nutrition of cells diffuses through the matrix. Cartilage has no nerves, it is therefore, insensitive. Cartilage is surrounded by a fibrous membrane called **perichondrium**, which is similar to periosteum in structure and function. When cartilage calcifies, the chondrocytes die and cartilage is replaced by bone like tissue. (Fig.16.3)

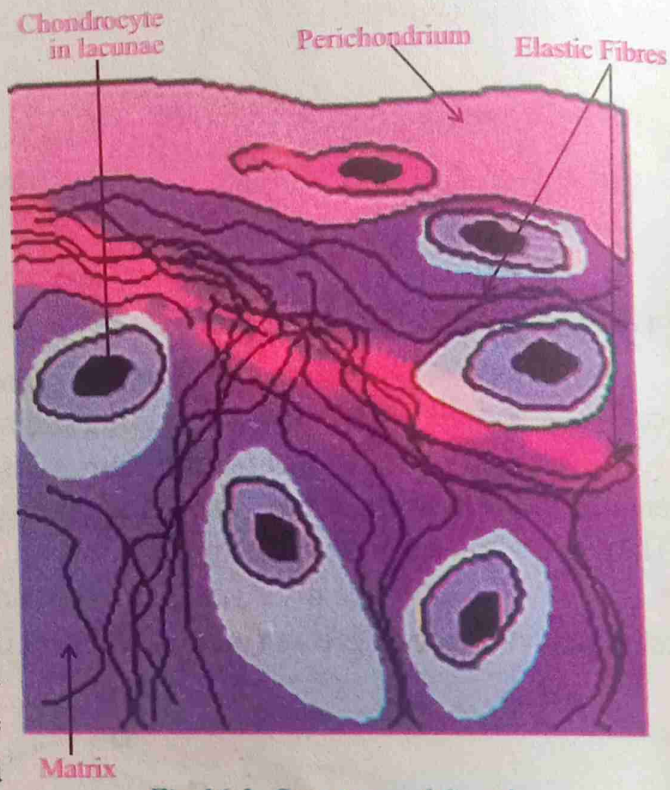


Fig.16.3: Structure of Cartilage

Table 16.1 The comparison between bone and Cartilage

S.No.	Bone	Cartilage
i)	Bone is hard.	Cartilage is soft.
ii)	Cells of bone are called osteocytes.	Cells of cartilage are called chondrocytes.
iii)	Matrix is inflexible.	Matrix is flexible.
iv)	Matrix possesses calcium salts.	Calcium salts are not present.
v)	Bone has rich blood supply.	It does not have blood supply.
vi)	Bone marrow is present.	Bone marrow is absent.
vii)	It is vascular in nature.	It is non-vascular in nature.
viii)	Outer covering is called periosteum.	Outer covering is called perichondrium.
ix)	Provide skeletal support to the body.	Provide flexibility to the body.

16.1.4 Joints

Joint is the point of attachment between two bones or bone and cartilage. There are more joints in a child than in adult because some of the bones fuse together as the growth proceeds. There are 360 joints in adult human skeleton. The scientific study of joints is called **arthrology**.

Extra Information

Ligaments are short bands of tough fibrous connective tissue that function to connect one bone to another bone in the joint.

Types of joints

On the basis of tissue present in the joint, there are three types of joints: fibrous joints, cartilaginous joints and synovial joints.

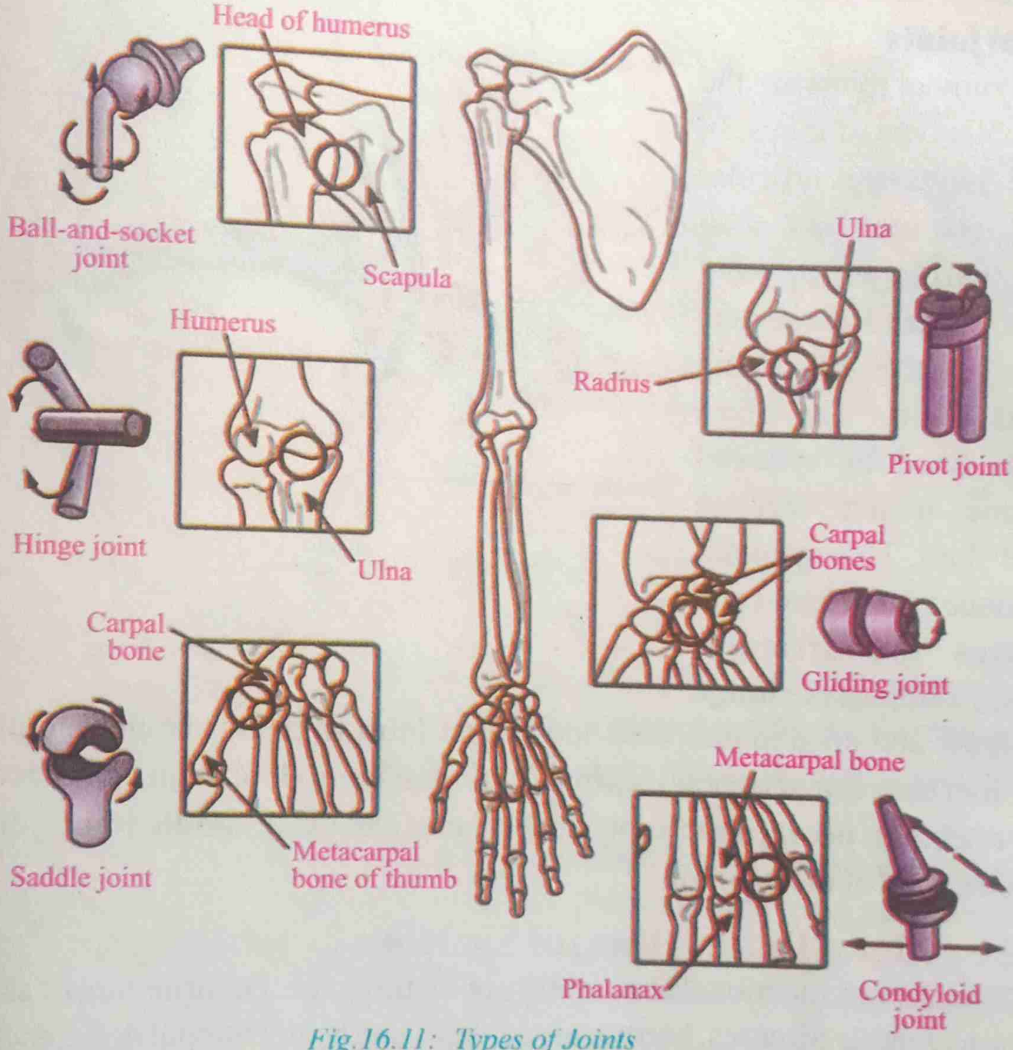


Fig.16.11: Types of Joints

Fibrous joints

When the articular surface of the bones are connected to each other by fibrous connective tissue, it is called **fibrous joint**. Fibrous connective tissue is a dense

connective tissue consisting mainly of collagen. These joints are also called immovable joints because they do not allow movement. Examples, includes joint between skull bones called **sutures**, joint between tooth and its socket and joint between long bones e.g. tibia and fibula.

Cartilaginous joints

When the articular surface of the bones is connected by cartilage (fibrocartilage or hyaline cartilage), it is called **cartilaginous joint**. These joints are also called **slightly movable joints** because they allow little movement. **Hyaline cartilage** is seen in the costal cartilages that attach ribs to the sternum, **fibrocartilage** is seen in intervertebral disc and pubic **symphysis**.

Synovial joints

Synovial joints are the most mobile type of joints. In synovial joints the articular surfaces are covered with hyaline cartilage. A joint cavity is present between the articular surfaces filled with synovial fluid. The joint cavity is lined by synovial membrane which secretes synovial fluid. This **synovial fluid** reduces the friction and lubricates the articular surfaces. Examples are **hinge joint** (elbow and knee joints), **ball and socket joint** (hip and shoulder joints), **gliding joint** (joints between vertebrae), **ellipsoid joint** or **condyloid joint** (joint between skull and 1st vertebrae), **pivot joint** (joint between atlas and axis), **saddle joint** (joint between carpometacarpal of the thumb).

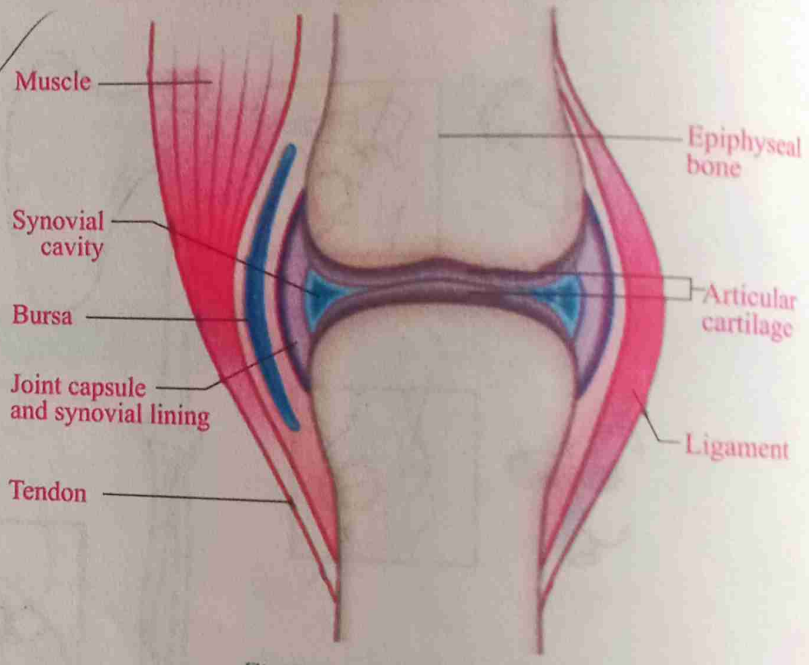


Fig.16.12: Synovial Joints

16.2 Disorders (Deformities) of Skeleton

Disorder is a functional abnormality or disturbance. Deformation of skeleton may occur due to genetic diseases, hormonal problems and by nutritional deficiencies.

16.2.1 Common Disorder of Skeleton

Some common conditions that affect the skeletal system include slip disc, spondylosis, sciatica and arthritis.

leg. Recovery from sciatic injury is usually slow and incomplete.

Common causes of sciatica include; a herniated disc, any injury to proximal sciatic nerve, **spondylolisthesis** (a condition in which one vertebra slips forward over another one), muscle spasm in the back or buttocks, improper administration of injection into the buttocks. The pregnant women have a great chance of getting a herniated disc and develop sciatica. Diabetes can also cause nerve damage.

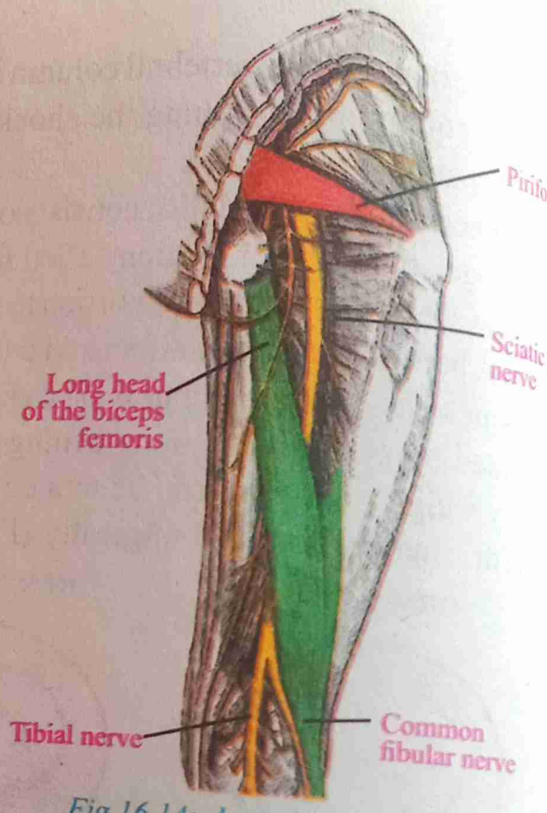


Fig.16.14: Location of Sciatic Nerve in Leg

Arthritis

Arthritis is the **inflammation of joint**. In this disease the joints become swollen, stiffer and painful. The membrane lining of the joint thickens, fluid production is decreased which leads to increase friction.

An infection or injury to the joints, abnormal metabolism and immune system dysfunction are the possible causes of arthritis. Sometimes, it may be caused by inheritance such as in **osteoarthritis**.

Chronic arthritis includes osteoarthritis, rheumatoid arthritis and gouty arthritis. **Osteoarthritis** is the most common type of arthritis. It can cause inflammation of any joint. It occurs when the joint cartilage is degenerated.

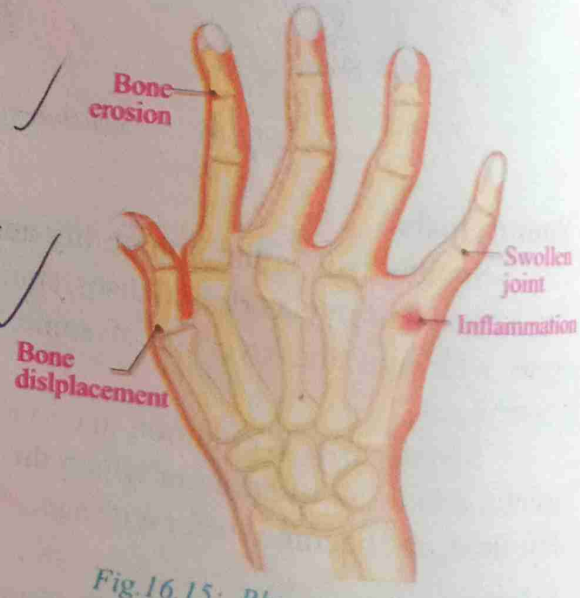


Fig.16.15: Rheumatoid Arthritis

Rheumatoid arthritis is the inflammation of hand and wrist joints. **Gouty arthritis** develops in people who have high level of uric acid in their blood. It is caused by the deposition of needle like crystals of uric acid in a joint.

16.2.2 Bone Fracture

When there is a partial or complete break in the continuity of the bone, it is called bone fracture. Fractures occur mostly when a bone is impacted by more force than it can

16.2.5 First aid treatment for fractures

First aid treatment is very useful for fractures as it prevents further injury and promote recovery. There are following first aid treatments for fractures.

1. Apply pressure to the injured area to control any bleeding. Pressure can be applied with the help of clean cloth or bandage.
2. Immobilize the injured area by providing support. This can prevent any further damage.
3. Apply ice packs to the injured part. This will limit swelling and relives pain. Don't apply ice directly to the skin, wrap the ice in a towel or cloth and apply it to the injured area for up to 10 minutes.
4. Keep checking the casualty for signs of shock. If the patient loses responsiveness, check his/her breathing rate and help patient get into a comfortable position.

Extra Information

The largest muscle of the body is gluteus maximum which is main extensor muscle of the hip. It supports the trunk and maintain proper posture.

16.3 Muscles

The muscle is a contractile tissue found in animals. The primary function of muscle is to produce movement. Besides movement muscles also hold body parts in postural positions, movement of the body fluids and heat production. The study of muscles is called **myology**.

16.3.1 Types of Muscle

There are over 640 muscles in the body of human which are divided into following three groups:

Skeletal Muscles

These are located on skeleton so called skeletal muscles. They are **voluntary muscles**, meaning that we can control them at will. They typically control movement

through activation by the somatic branch of peripheral nervous system with a rapid speed of contraction. Skeletal muscles also play a role in temperature regulation, using rapid muscle contraction. They are striated, meaning that its tissue is crossed with light and dark bands. They get fatigue easily. (Fig.16.17a)

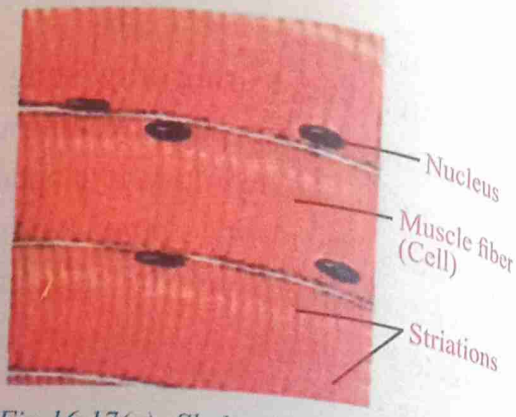


Fig.16.17(a): Skeletal Muscle

Smooth Muscles

Smooth muscles are **involuntary muscle** tissue controlled by the automatic nervous system. They are located in all visceral organs (except heart) such as the stomach, intestines, bladder as well as our blood vessels. Smooth muscle contracts more slowly than skeletal and cardiac. The function of smooth muscle is to move substance through an organ or vessel. It does so by contracting in waves, known as **peristalsis**. The cells of these muscles are **spindle shaped** with a single nucleus located in the middle of the cell. They do not get fatigue.

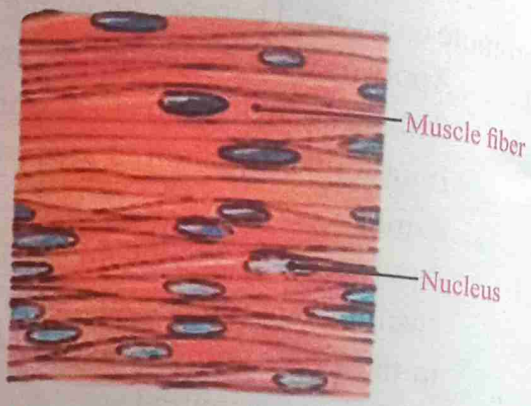


Fig.16.17(b): Smooth Muscle

Cardiac Muscles

They are located only in heart. They are involuntary muscles so controlled by autonomic nervous system. Like skeletal muscle, these muscle cells are also striated. In between its fibres are intermittent spaces, which contain connective tissues and many capillaries to ensure a constant supply of oxygen. The cells are **uninucleated** and branched. Adjacent cells joint together to form branching fibres by specialized cell to cell attachment called **intercalated discs**. The comparison of these three types of muscles are given in table 16.4. (Fig.16.17c)

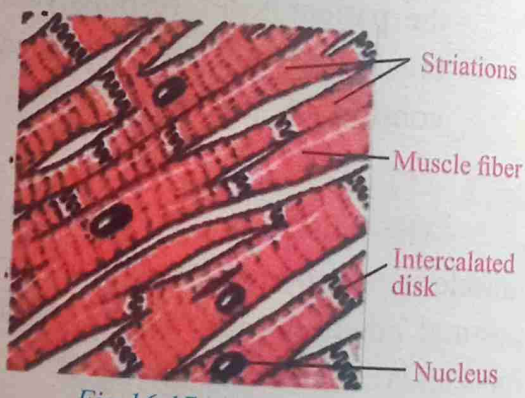


Fig.16.17(c): Cardiac Muscle

Extra Information

The hardest working muscle in the body are cardiac. The heart pump about 2500 gallon of blood per day.

Table 16.4: Comparison of Three Types of Muscles

	Skeletal	Cardiac	Smooth
Location	Attached to bones	The heart	Internal organs and skin
Shape	Elongated and cylindrical 	Branched 	Spindle 
Nucleus	Several peripherally located nuclei	Single centrally located nucleus	Single centrally located nucleus
Striation	Striated	Striated	Non-striated
Function	* Movement of bone * Heat production	Beating of the heart	Movement of the viscera
Control	Voluntary	Involuntary	Involuntary

16.3.2 Structure of skeletal muscles

Each skeletal muscle is attached with two bones. The end of skeletal muscle attached with immovable bone is called origin of muscle, while the other end of skeletal muscle is attached with moveable bone is called insertion of muscle. The muscle attaches with bone by a connective tissue known as tendon. Within a typical skeletal muscle is a bundle of long fibres running parallel to the length of muscle. Each fibre is a single cell with multi nuclei (each nucleus is derived from one of the embryonic cell). These embryonic cells fused to form the muscle cell. Inside a muscle cell lies a longitudinal bundle of myofibrils, which contain the thin and thick filaments. Each thin filament mostly consists of **actin filaments**. The thick filaments are called **myosin**. The **myofibrils** are made up of repeating sections called **sarcomeres**, which are the basic contractile units of skeletal muscle. Theborders of the sarcomere

Extra Information

The smallest muscles (stapedius) of the body lie in the ear along with smallest bone (Stapes), while the strongest muscle, based on its weight, is the masseter, in the jaw.

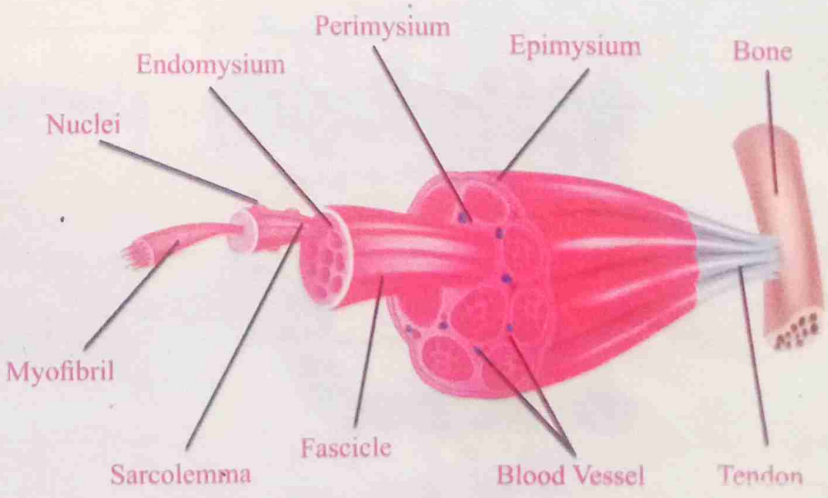


Fig.16.18: Structure of Skeletal Muscle

line up in adjacent myofi-brils, forming a pattern of light and dark bands (striations) visible with light microscope. That is why skeletal muscles are called **striated muscle**. The thin filament attached with **Z line** (zwisch line means between), while thick filaments are anchored at M-lines **(middle line)** centered in sarcomere. In relaxed state, the thick and thin filaments partially overlap. Near the edge of sarcomeres there are only thin filament and this portion of sarcomere is called I-band (isotropic). The zone of sarcomere in the center contains thick band and called A-band (Anisotropic) *i.e.* complete length of myosin partially covered by actin filament. The middle portion where only myosin filaments are present are called **H-Zone** (Hele Zone means bright). This arrangement is the key to how the sarcomere and whole muscle contract.

Ultra-structure of Skeletal Muscles

The sarcomere is the structural and functional unit of muscle fibre (muscle cell). A muscle fibre is a cylindrical cell which contains all the parts of a typical cell like plasma membrane (sarcolemma), cytoplasm (sarcoplasm), endoplasmic reticulum (sarcoplasmic retialum), mitochondria, nuclei, *etc.*

Extra Information

Muscles are built during sleep, not in gym or during exercise because at this time more blood circulation and hormones are released.

Under electron microscope, in the sarcomere two types of filaments are visible. Thick filaments are called myosin while thin filaments are called actin.

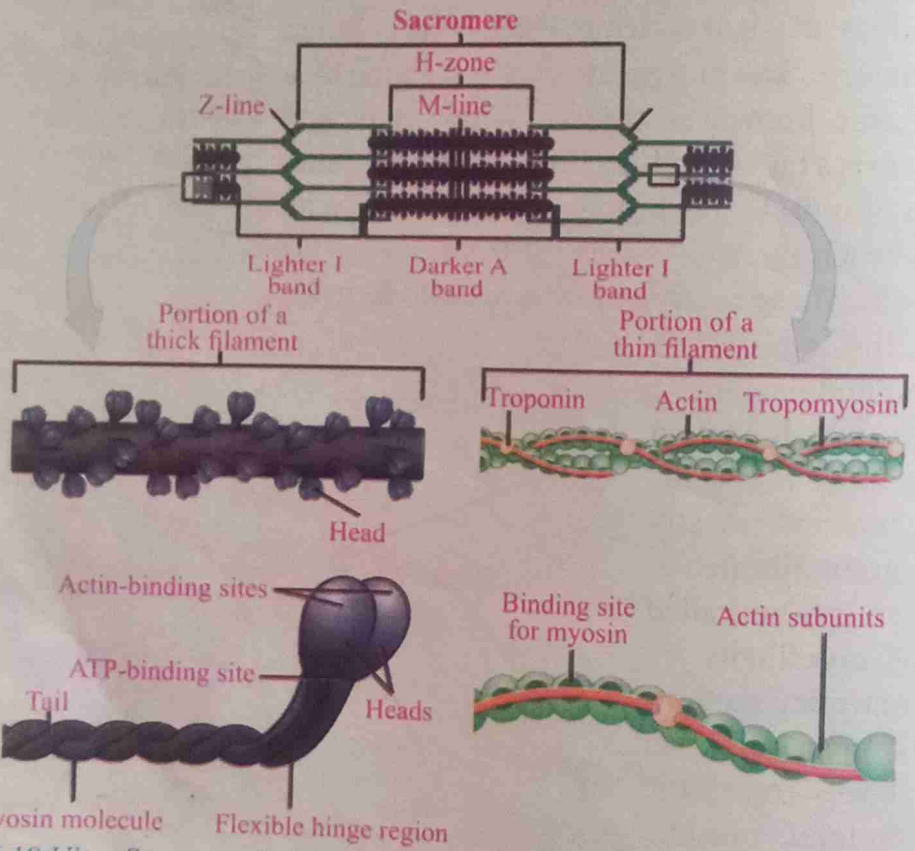


Fig. 16.19 Ultra Structure of Actin-myosin Filaments and Structure of Muscle Fibre

Myosin filament

These filaments consist of myosin protein. Each thick filament is 15nm in diameter. Each filament consists of hundreds of molecules of myosin protein. A myosin molecule is shaped like a golf club, with a tail formed of two intertwined chains and a double globular head projecting from it at an angle. Half of the myosin heads projecting from it at an angle to the left and half of them angle to the right, creating an area in the middle of the filament known as bare zone.

Actin filament

Thin filaments are called actin filaments. An actin filament is about 7nm in diameter, and consists primarily of actin protein. There are two chains of actin protein molecules twisted together, each actin filament also contains 40-60 molecules of **tropomyosin**, the protein which block the active sites of thin filaments when the muscle is relaxed. Each tropomyosin molecule has a smaller calcium binding protein called troponin, is bound to it. (Fig.16.19).

16.3.3 Muscle contraction – sliding filament model

According to sliding filament theory of muscle contraction, the actual length of actin and myosin filament does not change but actin filaments slide over myosin filaments. The actual trick is played by myosin filaments. This happens when myosin

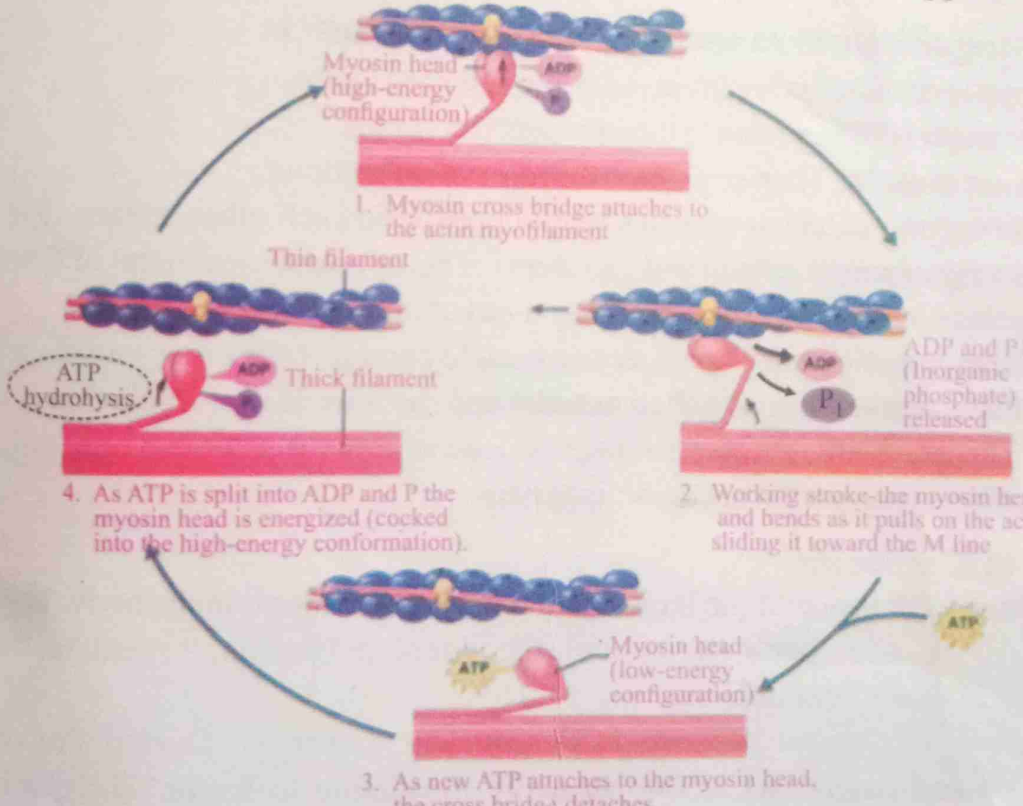


Fig.16.20: Sliding Filament Model

heads attach with actin filament at the site of troponin protein. When these heads bend, these pull the actin filaments over the myosin filaments. This theory was proposed by Z. Huxley and A.F Huxley in 1954. During full muscle contraction the I-band and H-zone disappear and only dark zone *i.e.* A-band appears. During the sliding process the Z-lines come close together and as a result sarcomere shortens. ATP provides energy for muscle contraction. The sliding filament theory or model is universally accepted. (Fig.16.20)

Control of Cross Bridges and Role of Calcium Ions

Muscle contraction is initiated when nerve impulse arrives at the **neuromuscular junction** within the muscle fibre, the action potential spreads deep into the interior, following infolding of plasma membrane called **transverse tubules** (T-tubules). These make close contact with the sarcoplasmic reticulum (SR). As the action potential spreads along the **T-tubules**, it triggers changes in SR, opening Ca^{++} channels. Calcium ions stored in the SR flow through open channels into the cytosol and bind to the troponin protein and cause them to slightly move. As a result, tropomyosin diphase and expose the binding site for myosin head. Once the myosin head attaches with actin filament, ATP is hydrolysed to adenosine diphosphate (ADP) and inorganic phosphate (Pi) and the cross bridges are broken down. The formation and break down of cross bridges occur again and again and movement of muscle occurs.

- Explain the principles
  CT scan and MRI.

Introduction

All animals show some common characteristics, one of these is to produce response to **stimuli** (*i.e.* any internal and external change). The activities of different body parts in response to the stimuli must be **coordinated**. The coordination makes possible the integration of functions essential to animal behavior. It is must for animals and human to survive. In human and most animals there are two types of coordination, *i.e.* nervous coordination and endocrine coordination. This unit deals with only nervous coordination.

17.1 Nervous System of Man

The study of nervous system is known as **neurology**. The working of different body parts with cooperation to each other and under the control of coordinator (Brain, Spinal cord or ganglia) is called **coordination.**

The system of the body that provides coordination through electric signal among different body parts during the response to a particular stimulus is called **nervous system**. The most developed, advanced and evolved nervous system among all organisms is that of human.

17.1.1 Steps Involved in Nervous Coordination

Nervous coordination involves highly specialized cells known as **neurons**, which are either connected together or via centralized nervous system to form a network that is linked to the receptors and effectors.

Nervous system in human and higher animals consists of three basic elements.

- **Receptors** are cells, tissues or organs which receive stimuli and give information to sensory neurons.
- **The neuron** has the capacity to generate and conduct impulses to central nervous system where processing / analysis of information takes place and pass responses to the effectors.
- **Effectors** are structures such as cells, tissues, muscles and glands which carry out action or make responses.

17.1.2 Receptors or Transducers

Receptors are organs, tissues, cells or nerve endings that detect changes (stimuli) in the external or internal environment of an animal *(e.g.* Human). These stimuli then transmitted to the brain or spinal cord through sensory neurons.

Classification of Receptors on the Basis of Stimuli

Receptors are classified into following five types.

- **Chemoreceptors,** which detect the concentration of certain chemicals or ions, *e.g.* CO_2 level in the blood by **medulla of brain**, O_2 level by **carotid body**. The chemoreceptors for blood glucose, amino acids, fatty acids are located in the **hypothalamus of brain**, smell **(olfaction)** in the nasal epithelium, taste **(gustation)** found in tongue and osmoreceptor (detect osmotic pressure of blood) in hypothalamus.
- **Mechanoreceptors,** which detect stimuli of pressure, body position or acceleration, include **Meissner's corpuscles** in skin for touch, **Pacinian's corpuscles** also in skin, **baroreceptors** in blood vessel for pressure and stretch also in, **ear** for hearing and equilibrium.
- **Thermoreceptors** are mostly located in the skin to detect change in temperature (cold/warmth).
- **Nociceptors** are pain receptors widely distributed in the skin and other internal organs which detect damage to body tissues.
- **Photoreceptors** or **electromagnetic receptors,** detect light stimuli, such as rods and cone cells in the retina of our eyes.

17.1.3 Processing / Analysis of Information

All types of sensory inputs from various receptors are conveyed to coordinator *i.e.* brain and spinal cord by sensory neurons. The information collected by them is processed and analysed, for a suitable response by special types of neurons known as inter or associated or relay neurons.

17.1.4 Effectors

Effectors respond to stimuli by impulse coming via motor neuron, such as

muscles and glands. The glands secrete some types of chemicals while muscles respond by contracting.

Stimulus Receptor Sensory neuron Inter neuron (CNS) Motor neuron Effector Response.

17.2 Neurons

Neurons are the chief structural and functional units of nervous system. In addition to neurons, nervous system contains neuroglial cells, which nourish the neurons and also protect the neurons by myelin sheath.

17.2.1 Structure of Neuron

A typical neuron consists of three basic components, *i.e.* cell body, axon and dendrites. The **cell body** or **soma or cyton or perikaryon of neuron** contain, nucleus and various cellular organelles except centrioles. The neuron cell body contains a mass of granular cytoplasm and enclosed by cell membrane (neurilemma). The nucleus is centrally placed. The cell body contains a group of ribosomes associated with rough endoplasmic reticulum and Golgi bodies known as **Nissl's granules** (these help in protein synthesis and acetyl-choline forming enzyme) These granules are absent in axon and Dendron. (Fig.17.1)

Interesting Information

Nervous system also cont-ains about 50% of neuro-glial cells.

The cell body of neuron is surrounded by cytoplasmic fibres, which are of two main types, *i.e.* axon and dendrites.

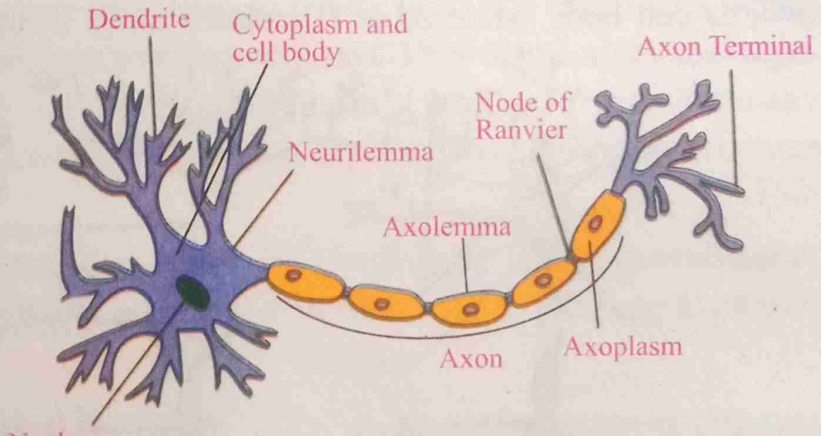


Fig. 17.1: A Typical Neuron

Axons are cytoplasmic process that conduct impulses away from cell body. Each axon is a usually thick long fibre (few mms to more than a meter in length) with a constant diameter. The cytoplasm of the axon is called **axoplasm** and cell membrane is called **axolemma**. Each axon terminates by branching to form small extension with knob like ending to cell presynaptic terminal. The neuroglia or glial cells that nourish, protect and support the neurons. In peripheral nervous system these cells are known as **Schwann cells**, which cover the axon by repeatedly wrapping it.

These cells are also covered by a fatty substance known as **myelin sheath**, which act as an insulator. Thus axons are called **myelinated fibres**. The non-myelinated portion of axon is called **node of Ranvier,** located between Schwann cells. The impulses jump from node of Ranvier to node of Ranvier, which are known as **saltatory impulses**.

Myelinated Fibres

It is transmit impulses much rapidly than non-myelinated neuron. It has larger and thicker axon because velocity of impulse depends upon the diameter, length and myelin sheath.

Dendrites are also cytoplasmic extensions that carry impulses towards the cell body. If they are single, then called **Dendron**. They are thin, short and mostly branched. The branches are gradually tapered from the base to their tips. The gap between dendrites of one neuron and axon terminals of another neuron is called **synapse**.

17.2.2 Types of Neurons

On the basis of functions, the neurons are of three types, *i.e.* sensory neurons, inter neurons and motor neurons.

i) Sensory Neurons conduct impulses form receptors to central nervous system. These are **unipolar** because only one fibre **originating** from cell body which immediately gives rise to two branches, one towards receptor and other towards central nervous system. Both fibres are structurally axon like except their terminal portions differ that is one is like dendrites and other is like axon. One (axon) carries impulse towards cell body while other (Dendron) away from cell body. Majority of sensory

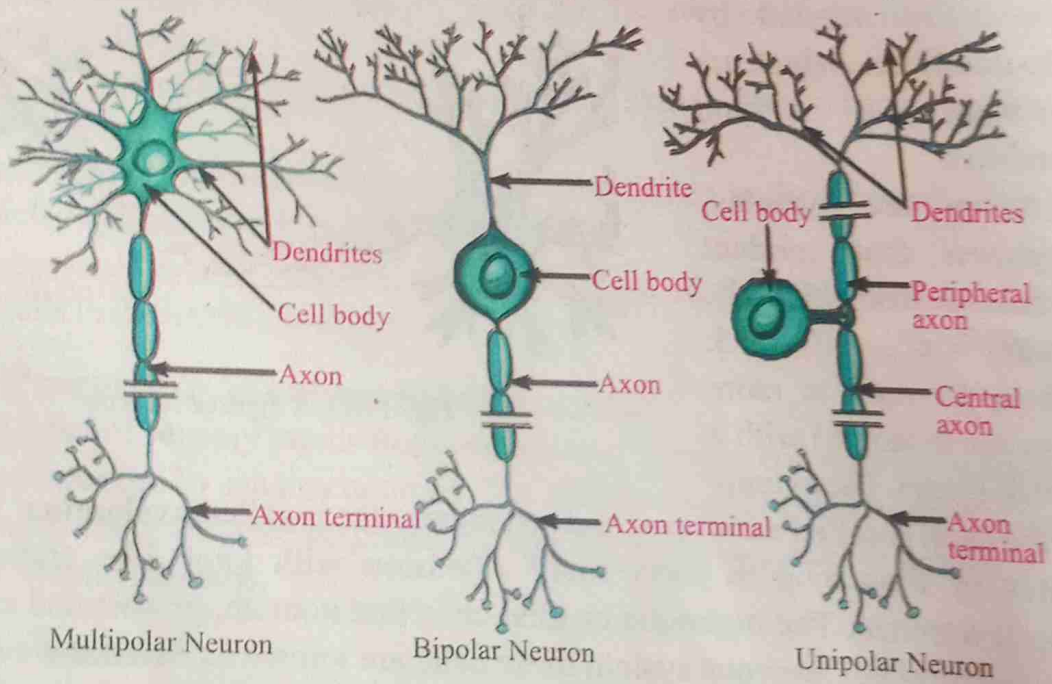


Fig. 17.2: Multipolar, Bipolar and Unipolar Neurons

neuron are unipolar but some are bipolar. The unipolar neurons are found specially in dorsal root of spinal cord. (Fig.17.2)

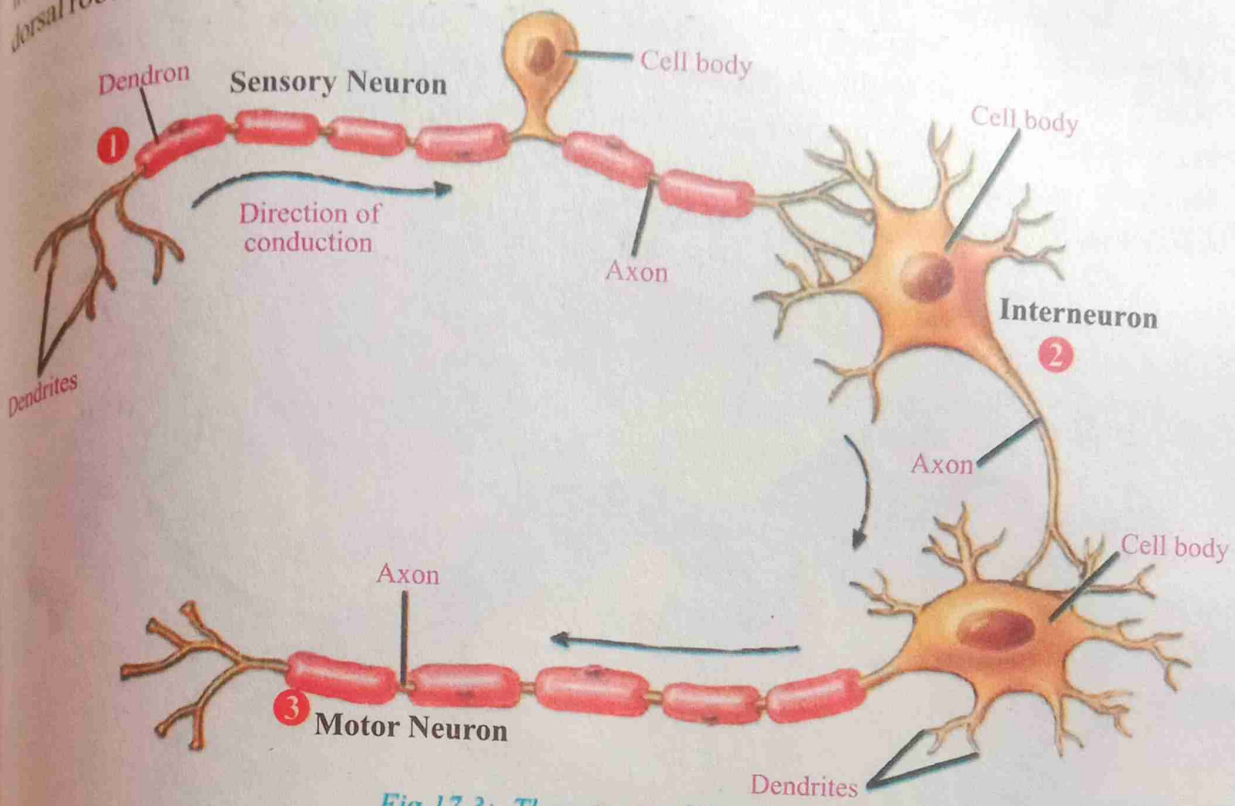


Fig.17.3: Three types of Neurons

ii) **Associated or Interneurons** are found only in the brain and spinal cord. These conduct impulses from sensory neurons to motor neurons. They also convey messages between various parts of the CNS. Inter neurons are mostly **multipolar** because many fibres arises from cell body. Their axon is thin and non-myelinated, while many dendrites carry impulses to its cell body.

iii) **Motor Neurons** conduct impulses from CNS to effectors. These are **multipolar** neurons. Their cell body contains many branched dendrites and a single long axon runs towards effector. (Fig.17.3)

Myelinated and Non-Myelinated Neurons

Myelinated neurons (Nerve fibres) are covered by fatty layer known as myelin sheath (axons) whereas non-myelinated neurons do not have a myelin sheath (Dendrites and Cell bodies). In myelinated neurons conduction of impulses are faster than non-myelinated neurons. Inter neurons are non-myelinated while motor and sensory neuron have myelinated portion.

Myelinated Neurons

The impulse jump from node of Ranvier to node of Ranvier. This is called saltatory impulse. Nerve impulse is 20 times faster in myelinated neuron than non-myelinated neuron.

17.2.3 Reflex action and Reflex arc

Reflex action or Reflexes are involuntary, automatic, unconscious or immediate response to external or internal environmental change or stimuli. The pathway through which a reflex travel is called **reflex arc**. The direction of reflex action is from receptor to sensory neuron to CNS to inter neuron and then through motor neuron to the effectors. Reflexes have no involvement of conscious portion of brain, therefore, the response is quick than the conscious pathway. (Fig.17.4)

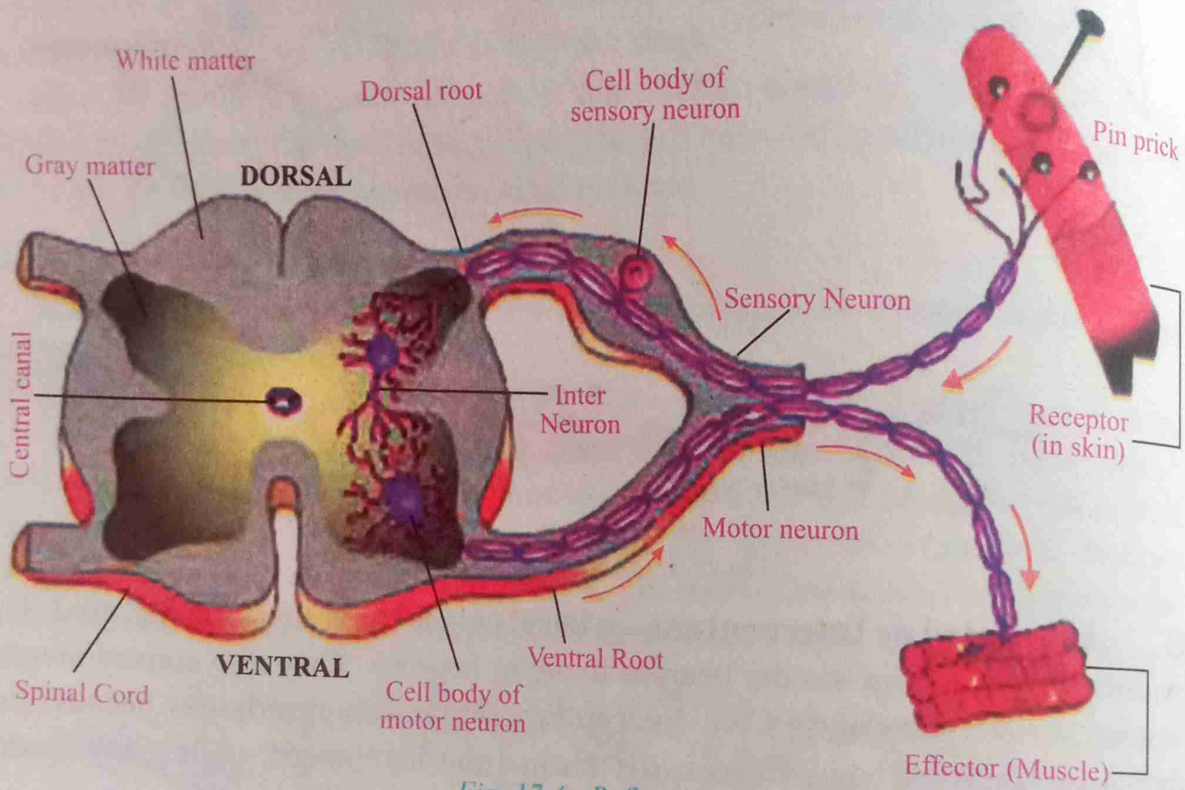


Fig. 17.4: Reflex Arc

Example of Reflex arc: If we unexpectedly touch a hot object or pin prick, our hands are rapidly removed from it. The receptors of our hands are activated by heat of the object. This impulse is conveyed to sensory neuron leading to spinal cord via spinal nerve then to inter neuron which lies entirely within the spinal cord. The inter neuron then passes this impulse to motor neuron then to effectors, *i.e.* muscles which causes them to contract. (Fig.17.4)

17.3 Nerve Impulse

Nerve impulse is the information about a stimulus that is transmitted from receptors to CNS and from CNS to the effectors. It is a wave of electrochemical change which runs along the length of the neuron,

Extra Information

Refractory period lasts for about four millise-conds so as a neuron can conduct 250 impulses per second.

involving chemical reactions and movement of ions across the **neurilemma**. The measurement of the capacity to do electrical work is known as **electric potential**. It represents a type of stored energy produces during separation of charge through a barrier. The charges are positive or negative, which act as separating barrier in the plasma membrane of neuron (Neurilemma).

Oscilloscope

It is an instrument with a screen which display changes in the voltage on both side of plasma membrane of neuron with time. The electric potential which exists across a cell membrane is known as **membrane potential**. The membrane potential is either resting membrane potential (RMP) or action membrane potential (AMP).

Extra Information

In human, normally the speed of flow of impulse in neuron is about 100-120m/ second.

17.3.1 Resting Membrane Potential

A typical neuron at rest or non-conducting neuron is called resting membrane potential. In this case a typical neuron is more positive electrically outside than inside the plasma membrane while inside is more negative as compared to outside the plasma membrane. It measures about – **70 millivolts (- 0.07 volt)**.

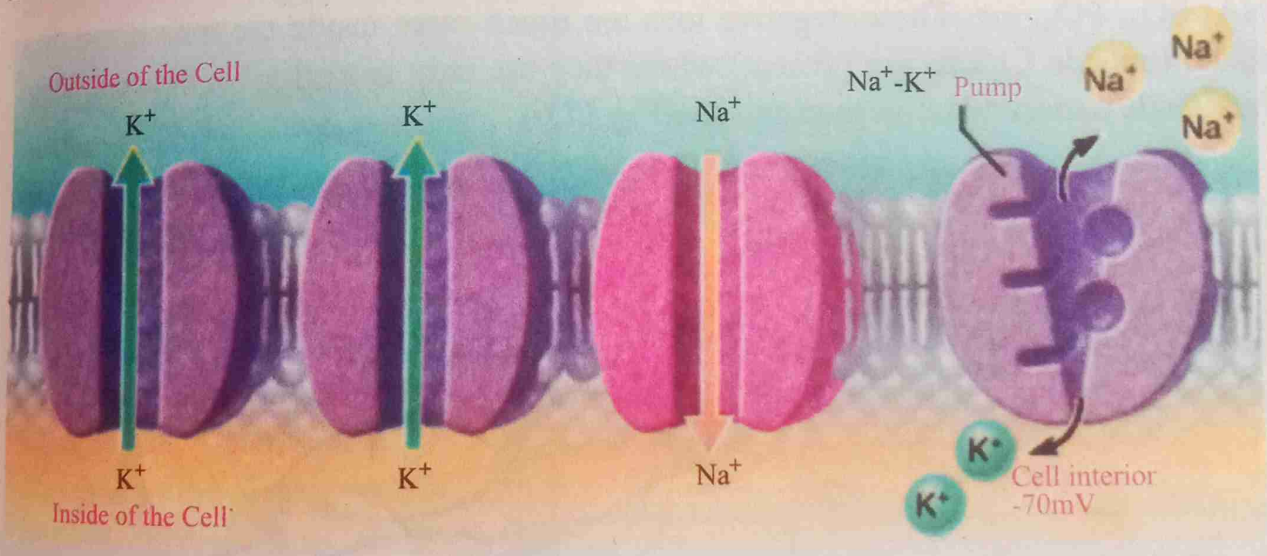


Fig. 17.5: Resting Membrane Potential (RMP)

Factors Involved in Resting Membrane Potential (RMP)

Major factors that are involved in RMP are:

Sodium and Potassium ions

There are many kinds of ions which are present inside and outside the plasma

membrane of neurons but the most important is sodium (Na^+) and potassium (K^+) ions. Sodium ions are tenfold higher in concentration outside than inside the membrane, whereas potassium ions are thirty fold higher in concentration inside than outside the membrane. The membrane of all the nerve cells possesses sodium and potassium pumps to transport these ions with the help of energy (ATP) against their concentration gradients. For every two potassium that are actively transported inside the membrane, three sodium ions are pumped out. Thus inside become more negative (70 mV) than the outside of the plasma membrane of nerve cell, which is more positive electrically than inside the membrane.

Table 17.1: Ionic Concentration Inside and Outside of Resting Neuron

Ingredients	Concentration (mmol/L)	
	Inside	Outside
Sodium ions	15	145
Potassium ions	150	5
Negative ions	156	30

Negative Organic Ions

Many types of large negative organic compounds are present in the both sides of plasma membrane of neurons. These organic ions include some proteins, amino acids, RNA, SO_4, PO_4, *etc*. These negative ions are much more inside the membrane than outside (outside Cl ions are present) where they are only in negligible concentration. Thus inside is more negative than outside.(Fig.17.6)

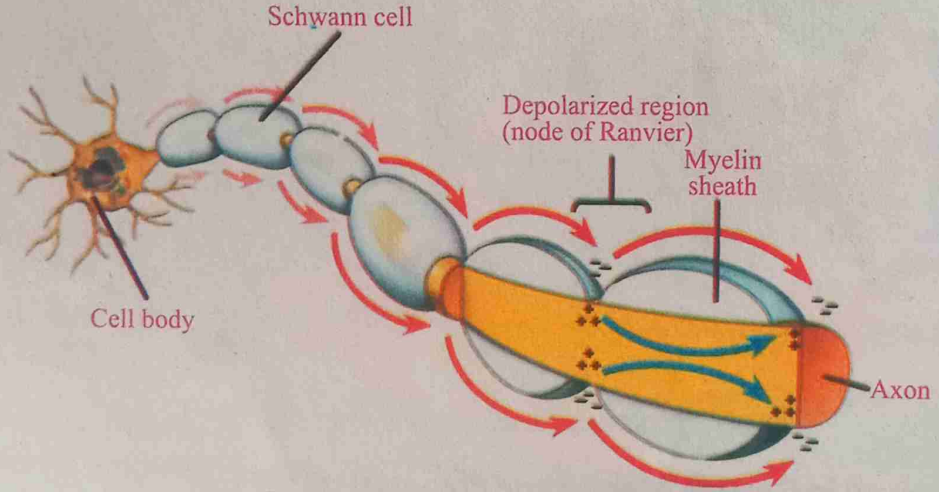


Fig. 17.6: Depolarized Region and Saltatory Impulse

Channel Proteins (Gates) in Plasma Membrane of Neurons

The plasma membrane is virtually impermeable to all ions except potassium ions.

It is slightly permeable to potassium, so it leaks out of the neuron by diffusion. That is why inside becomes more negative than outside of the plasma membrane of neuron. Thus non-conducting neuron is in **polarized state** (*i.e.* RMP – 0.07 volts or 70 mV). The resting membrane potential (RMP) will be maintained in undisturbed membrane. If it is disturbed or stimulated by a sufficient stimulus known as **threshold,** then action potential will occur.

17.3.2 Action Membrane Potential (AMP) (Depolarized State)

In action/active membrane potential, inside of neuron become more positive and outside become more negative. It is called depolarized state, which happen when appropriate stimulus receives, the positive charge sodium ion tends to move inside of the neuron. The electrochemical change is so brief (about one millisecond) that only a portion of the neuron (*i.e.* one node of Ranvier to another node of Ranvier) is in the action membrane potential state followed by the recovery of polarized state, thus impulses flow from one node of Ranvier another to node of Ranvier.

The major factors involved in changing the resting membrane potential to action membrane potential are:

1. Threshold Stimulus

It is capability of a stimulus to bring electrochemical charge on neuron or to excite a given tissue. It is also known as **adequate stimulus** (about – 50 to -55 mV electric membrane potential). If stimulus is not capable to excite or not appropriate, then it is called sub **threshold or inadequate stimulus**.

Influx of Na^+ ions

When threshold is reached, the membrane become more permeable to Na^+ than to the K^+ due to the opening of Na^+ gates. Thus influx of Na^+ ions by diffusion occurs, and electric potential of the membrane changes from -70 mV towards zero and then reach to about 50mV. This reversal of polarity

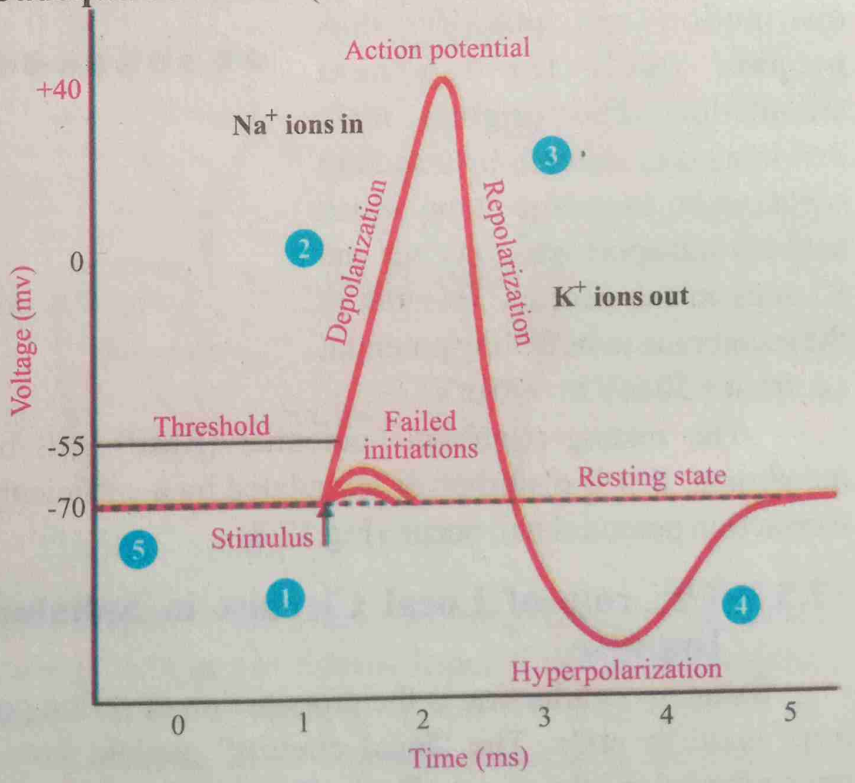


Fig. 17.7: Flow of Impulse

across two sides of membrane is called **depolarization**. This state of electropositive inside and electronegative outside lasts for about one millisecond till the Na^+ gates are not closed.

Interesting Information

The continuous impulse occurs in non-myelinated neuron fibres in which K^+ and Na^+ ions can move across the memb-rane along the length of neuron so action poten-tial flow as a wave.

Repolarized state

After the peak of action potential, called the **spike potential**, the permeability of Na^+ decreases, and now become more permeable for K^+ by opening of K^+ gates thus K^+ rapidly diffuses out from cytoplasm to extracellular fluid. The sodium gate closes and the neuron get its original polarity *i.e.* **repolarized** (inside more electro negative and outside more electro positive). Infact, there is a slight overshoot into a more negative potential than original resting potential. This is known as **hyperpolarized** state. It is due to the slight delay in closing of all K^+ gates compared with Na^+ gates. (Fig.17.7)

Refractory Period (Resting State)

It is a period when after an action potential, nerve fibre undergoes a period of recovery, in which it regain the original ionic distribution and polarity, thus prepare itself for the next stimulation. The original ionic distribution is restored by a sodium – potassium exchange pump which actively transport Na^+ ions out and K^+ ions in the neuron. This return the membrane to its resting potential *i.e.* from + 50 mV to – 70 mV.

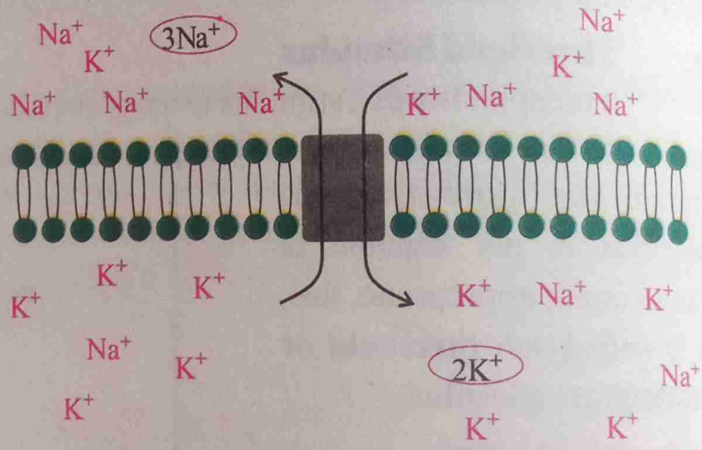


Fig. 17.8: Refractory Period of Neuron

The resting membrane potential (RMP) will be maintained in undisturbed membrane. If it is disturbed or stimulated by a sufficient stimulus known as threshold, then action potential will occur. (Fig.17.8)

17.3.3 The role of Local Circuits in Saltatory Conduction of Nerve Impulse

Saltatory conduction is the propagation of action potential along myleinated axon from node to node. The "local circuits" explain how the action potential (AP) is transmitted along the neuron. Basically an action potential at a point in the axon, develops

a local circuit because, the influx of sodium ions at that point makes that particular point positively charged. However, regions around that point are still negatively charged (because they are still in the "resting potential formation"). The sodium ions at the point of AP are then attracted to these negatively charged regions, hence setting up a "local circuit" at those regions. This circuit then opens the sodium channels at these points, sodium ions flow in and the whole AP circle continues, hence the AP moves along the axon.

17.4 Synapse

There is no cytoplasmic connection between successive neurons, however, impulses are transmitted and this transmission occur at synapse. **Synapses** are microscopic gap between successive neurons. These gaps are between axon terminal of one neuron and dendrites of another neuron. (Fig.17.9)

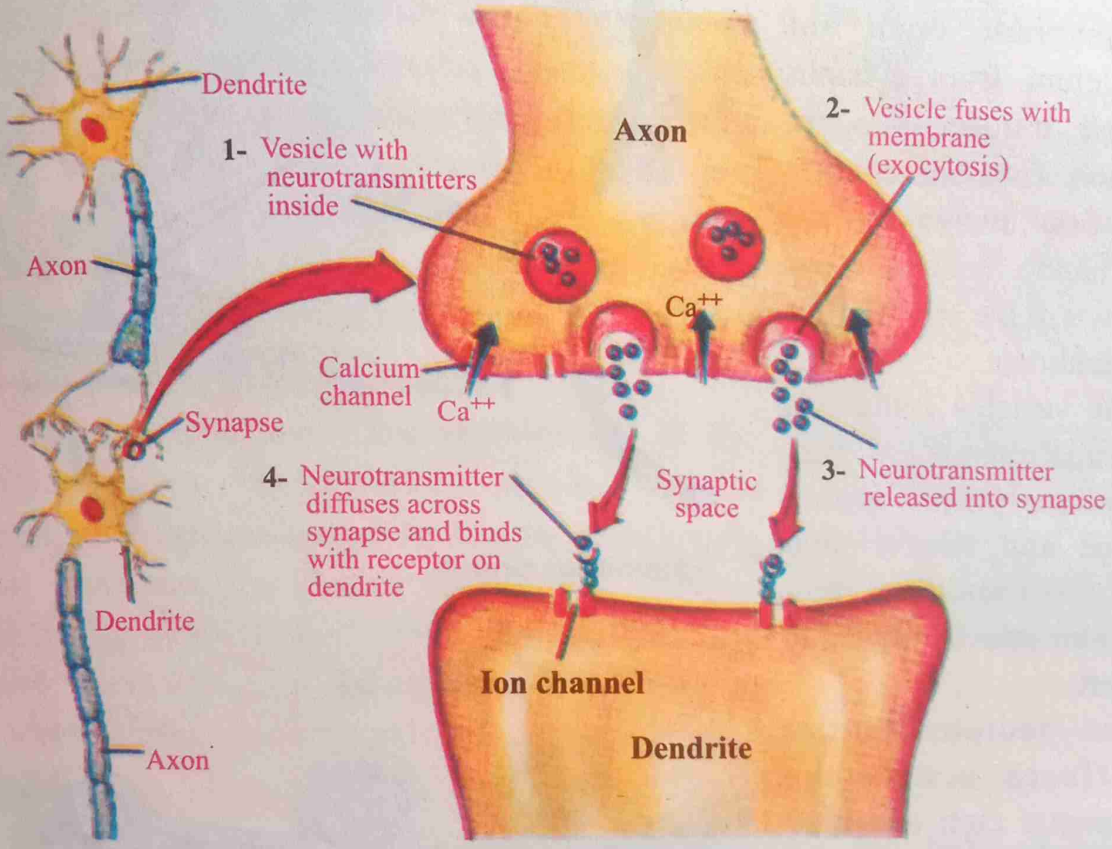


Fig. 17.9: Synapse

A single neuron may form synapses with many incoming fibres of different neurons. The gaps between successive neurons are cleave-shaped thus called **synaptic cleft.** A neuron carries information (impulse towards a synaptic cleft known as **transmitting neuron** or **presynaptic neuron** while a neuron which gets the impulse from synaptic cleft, is called **post synaptic neuron** or **receiving neuron**. The axon

terminals of each presynaptic neuron have expended endings called **knobs** which contain many spherical sacs, known as **synaptic vesicles**. Each vesicle contain as many as 10,000 molecules of chemical messengers, the **neurotransmitter substance**. The dendrite of post synaptic neuron lacks these vesicles. The transfer of impulse across the synapse is called **synaptic transmission.**

Steps of Mechanism of Synaptic Transmission

1. When action potential reaches the axon terminal, it is received by synaptic knob. The calcium channels, present in the presynaptic membrane open and calcium from synaptic cleft transfer into the knob. Thus Ca^{++} concentration increases, the synaptic vesicles move towards the pre-synaptic membrane.
2. The vesicles containing neurotransmitter fuse with presynaptic membrane and release their neurotransmitters molecules into the synaptic cleft.
3. The neurotransmitter diffuses across the synaptic cleft and bind to receptor molecules on postsynaptic membrane.
4. The receptor of post synaptic membrane, opens some channels and allow sodium ions to diffuse across the

Extra Information

There are 100 known types of neurotransmitters.

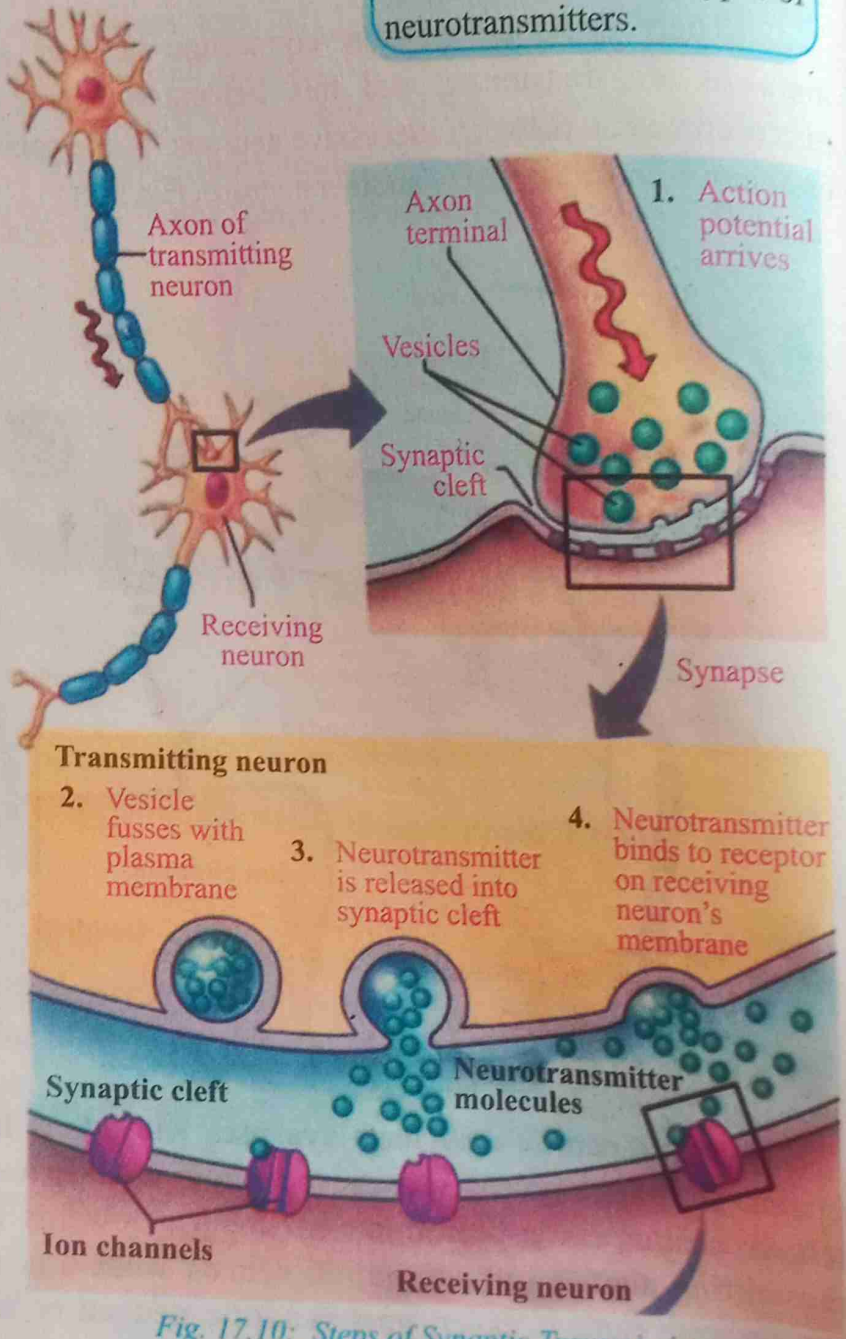


Fig. 17.10: Steps of Synaptic Transmission

postsynaptic membrane. As a result post synaptic membrane depolarizes *i.e.* (inside + outside -) and action potential is generated. Since this depolarization brings the membrane potential towards threshold level, it is called **Excitatory postsynaptic pot-ential (EPSP).**

5. After the activation of post synaptic membrane, the neurotransmitters are immediately broken down by enzymes (like acetylcholinesterase for acetylcholine and monoamine oxidases for adrenaline). (Fig.17.10)

17.4.1 Classification of Neurotransmitters

There are two major classes of neurotransmitters.

1. Excitatory Neurotransmitters

These initiate nerve impulses, cause increased membrane permeability to sodium ions. They may be **acetylcholine** for peripheral nervous system, **biogenic amine** (derived from amino acids) for central nervous system. Their types are **epinephrine** and **nor epinephrine** for heart beat rate during stress; **serotonin** and **dopamine** affect mood, sleep, attention and learning. All of these function like hormones.

2. Inhibitory Neurotransmitter

This decrease membrane permeability to Na^+ ions, which result to raise threshold of stimulus. Thus the nerve impulse does not trigger or lessens, to adjoining neuron. Examples are glycine amino acid, gamma-amino-butyric acid (GABA), while the endorphin are peptides, decreases pain reception and act both as neurotransmitters and hormones.

Interesting Information

There are two types of synapses.

1. **Electrical synapses**, which are rapid and synaptic cleft is only 0.2 nm thick.
2. **Chemical synapses**, in which gap is 20 nm. Thus transfer of impulses occurs by neurotransmitters (Chemicals).

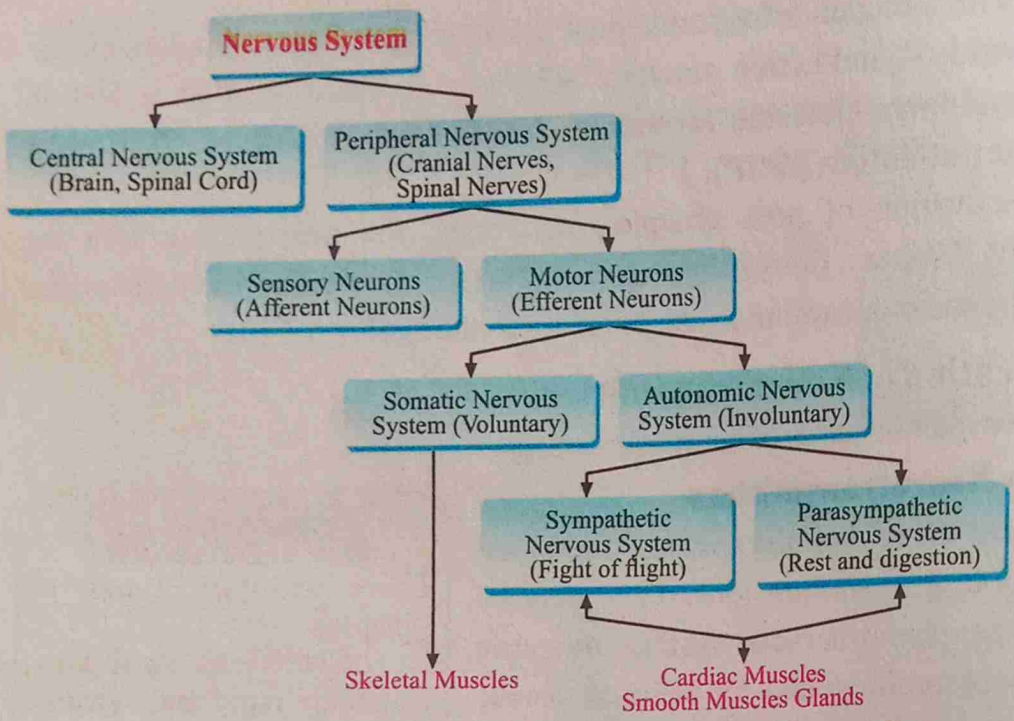
Extra Information

Coelenterates and echinoderms possess diffused nervous system.

17.5 Human Nervous System

Human and most animals (except coelenterates and Echinoderms) have centralized nervous system. Human nervous system is most advanced and also possess some unique features, *i.e.* enable us to convey our complex ideas, information and messages in the form of language, make and use various tools, preserve information (in written and video), great learning, memory storage capacities, *etc.*

Human nervous systems consist of two primary divisions, the central nervous system (CNS) and peripheral nervous system (PNS). (Flow chart 1)



Flow Chart.1: Classification of Human Nervous System

17.5.1 Architecture of Brain and Spinal Cord and their functions

Central Nervous System of Human (CNS)

It consists of brain and spinal cord, act as coordinating centre, these lies in the skull (Brain) and above the vertebral column (spinal cord) *i.e.* in midline of the body.

CNS is hollow and fluid filled. The brain has four cavities called **ventricles** while the cavity of spinal cord is known as **central canal.** The fluid in these cavities named as **cerebrospinal fluid (CSF)** (similar to blood plasma) act as cushion and bathes the neurons of CNS.

Protection of Central Nervous system

The brain is protected by bony cranium of skull while spinal cord is protected by vertebrae of vertebral column. Both brain and spinal cord are also covered by three membranes, collectively known as **meninges (singular; meninx)**, the outer hard **Dura matter** (next to cranium), inner **pia matter,** next to brain and spinal cord and middle **arachnoid matter.** The cerebrospinal fluid is present between the piamatter and arachnoid matter.

Interesting Information

Cerebrum is the largest part of brain and contains highest number of neurons than any other part of brain.

According to "Roger Spray"

Both cerebral hemisphere of cerebrum superficially same but right and left portion function so differently that we could almost say we have two brain in one. Left cerebrum house our language centre, logic mathematical abilities while the right hemisphere imagination, spatial perception, artistic and emotional abilities.

Brain

The brain of human can be divided into forebrain, mid brain and hind brain. (Fig.17.11)

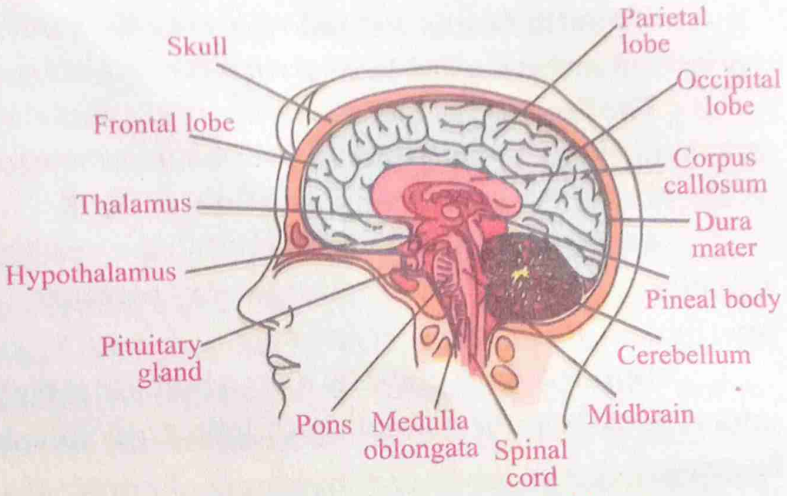


Fig. 17.11: C.S. of Brain of Man

Fore Brain

Forebrain has two sub-divisions; **telencephalon** (cerebrum) and **diencephalon** (thalamus and limbic system). The **cerebrum** of human is largest among all other animals (more than half of the brain). It is divided into two cerebral hemispheres, which are connected together by a band of axons known as **corpus-callosum**. It carries memory available on one side of the brain to the other side. Cerebrum contains four lobes, frontal, parietal, temporal and occipital lobe. The left cerebral hemis-phere controls the right side of the body while right cerebral hemisphere controls left side of the body. Functionally, cerebrum consist of **sensory area**, (receive impulses from receptors), **motor area** (give responses) and **associated area** (interprets or analyses the incoming information) cerebrum act as control centre for sight, smell, taste, speech and hearing. It also controls voluntary movements, thinking, learning, conscious sensations, judgment, reasoning, decision-making, dreams, emotional feeling, intelligence, analysis and interpretation of memory.

Extra Information

There are convolutions (groove) called gyri which are seen on outer part of cerebrum (cerebral cortex). The deep grooves are called fissure while shallow grooves are called sulcus. These grooves greatly increase the surface area of cerebrum. A longi-tudinal fissure is present between two parts of cerebrum.

Although the motor sensory and associated areas are located in all parts of cerebrum, however motor areas are more abundant in frontal lobe. The associated areas are most occupy the anterior of frontal lobe and wide spread in lateral portion of parietal, temporal and occipital lobes.

Diencephalon (Thalamus and limbic system): **Thalamus** lies below the cerebrum, act as relay centre and carries sensory impulse to the cerebrum and limbic system. Thalamus receives all sensory impulses (except sense of smell).

Limbic System

This system is located in an arc just under cerebrum. The limbic system consists of hypothalamus, amygdala, hippocampus and some part of cerebrum.

Hypothalamus located on the ventral side of thalamus. It is both nervous and endocrine centre *i.e.* link between nervous and endocrine centre.

The function of hypothalamus is to maintain homeostasis and contains centres for regulating body temperature, water balance, menstrual cycle, blood pressure, sleep wake cycle, hunger, sexual response and fight or flight.

Amygdalae are two almond shape masses of neurons on either side of the thalamus. It produces sensation of pleasure, sexual arousal when stimulated, punishment, love, hate, fear and rage.

Hippocampus consists of two horns that curves back from the amygdala and play important role in the formation of long term and short term memory, thus required for learning.

Mid Brain

In human this portion of brain is reduced. It contains auditory relay centre and centre that control reflex movement of eyes also contains auditory reflex centre. Mid brain contains reticular formation, which is a relay centre connecting fore brain with hind brain and is very important in screening the input information before they reach higher brain centres. (Fig.17.12)

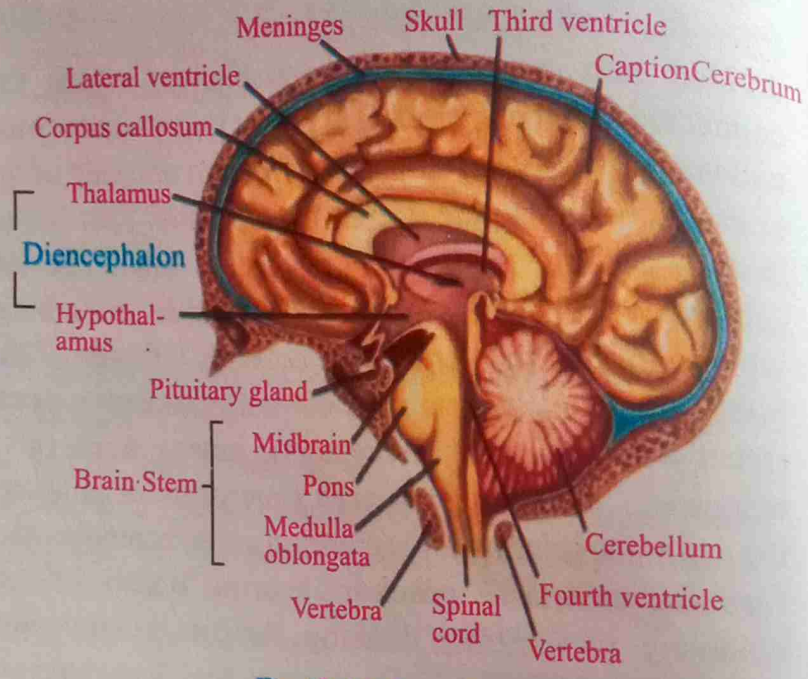


Fig.17.12: Brain Stem

Hind Brain

Hind brain includes the **pons, cerebellum** and **medulla.**

Pons is a group of neuron, located above the medulla; act as a bridge between cerebellum, medulla and cerebrum.

It is involved in rate and pattern of breathing, sleep and wakefulness.

Cerebellum is second largest part of the brain, bulb or leaf like in shape. It coordinates body movements and maintains body position *i.e.* equilibrium. The cerebellum guides, smooth and accurate motions and maintains body position. It also involves in the learning and memory storage for behavior. It is best developed in bird, which engages them in complex activity of flight.

Medulla is last part of brain but in evolutionary point of view, it developed first. It controls several automatic functions, such as heart beat rate, blood pressure, breathing and swallowing.

The mid brain, together with pons and medulla know as **brain stem**, which support the life.

Ventricles of Brain

Human brain possesses four ventricles or cavities, which are filled with cerebrospinal fluid. The first and second ventricles are present between limbic system and cerebrum known as **lateral ventricles**. Another ventricle is present between limbic system and thalamus called **third ventricle** while **fourth ventricle** is present in medulla. There is a tube between third and fourth ventricle known as **iter or cerebral aqueduct**, while an opening between lateral ventricles and third ventricle is called intra **ventricular foramen**. (Fig.17.13)

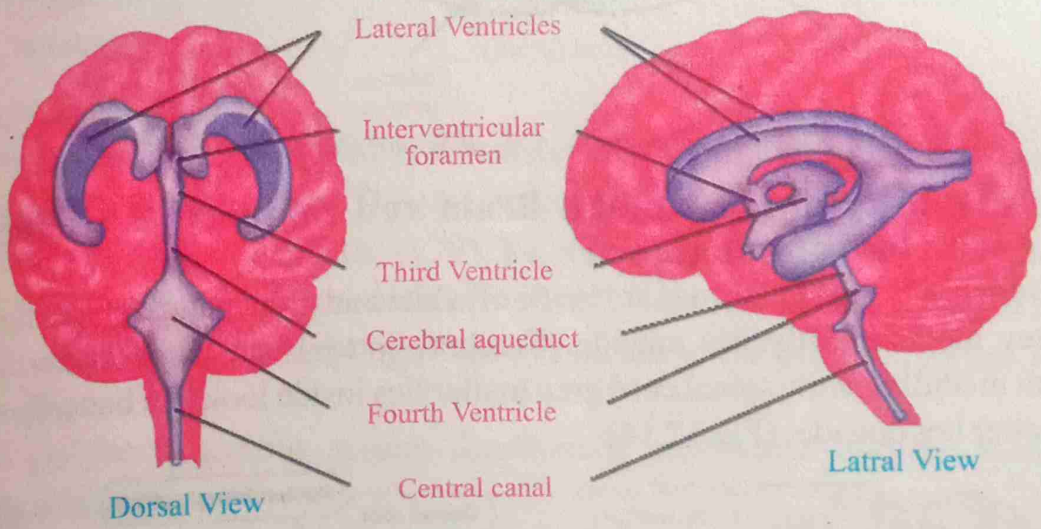


Fig. 17.13: Ventricles of the Brain

17.5.2 Spinal Cord

Medulla narrows down into the spinal cord. It is an elongated, hollow fluid filled and cylindrical structure, extends from the **foramen magnum** (a hole in the bottom of skull) lying in the neural canal of vertebral column (up to 3rd lumbar vertebrae). In a cross section of spinal cord exhibits inner butterfly shaped **grey matter** while peripheral **white matter**. There is a tiny central canal in the centre of grey matter, filled with CSF around the **central canal** is a single layer of cells called **ependymal layer**.

> **Interesting Information**
>
> Local anaesthesia is given at fourth lumbar, so as to protect the spinal cord.

The grey matter consists of non-myelinated portion *i.e.* mostly cell bodies of

neuron while white matter is composed of myelinated nerve fibres *i.e.* mostly axons. Spinal cord controls reflexes below the neck region. It also conducts impulses to and from the different part of the bodies and brain. Thus helps in better function of brain. (Fig.17.14)

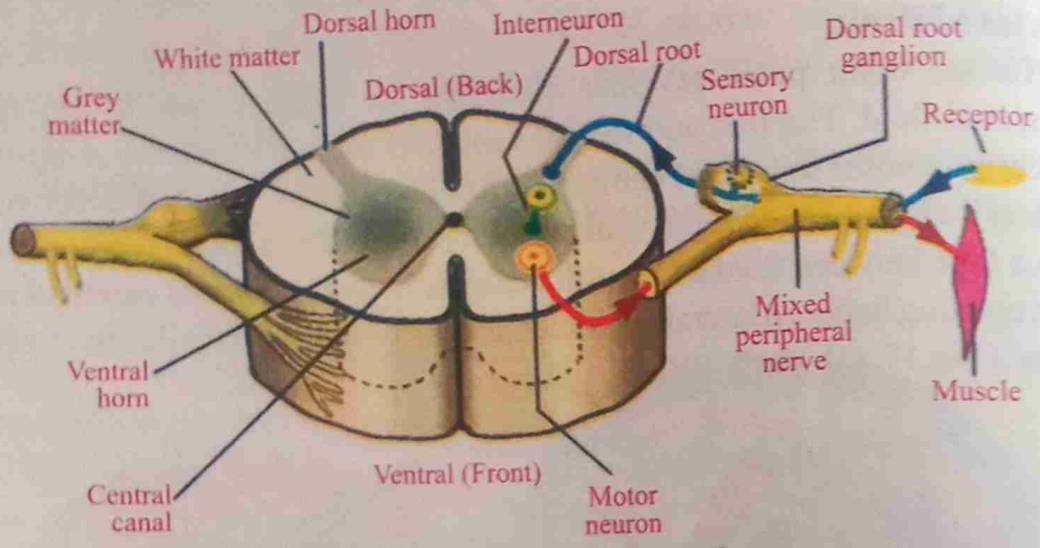


Fig. 17.14: C.S. of Spinal Cord

17.5.3 Architecture of Human Brain and compare its sectional view with that of spinal cord

Both brain and spinal cord are made of white and grey matter. The difference is in brain grey matter mostly lies outside (Cerebral cortex) and white matter lies inside (Cerebral medulla) while spinal cord grey matter lies inside look like butterfly shape and white matter lies outside . (Fig.17.14)

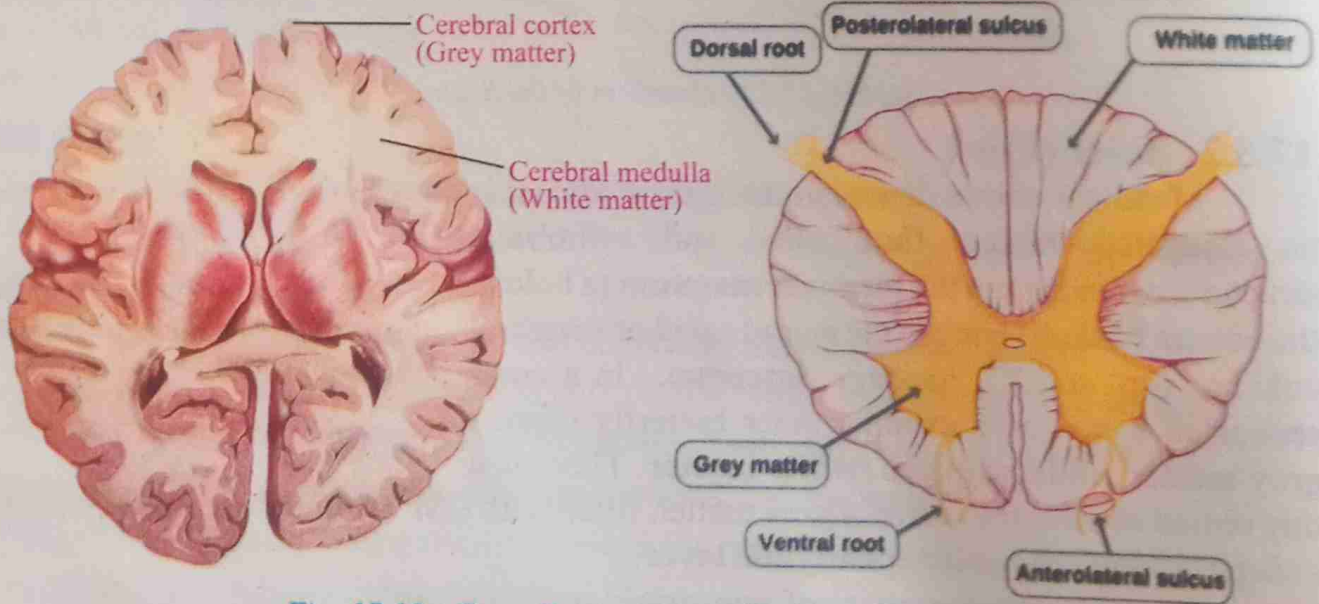


Fig. 17.15: Cross Section view of Brain and Spinal Cord

17.5.4 Peripheral Nervous System

It is the system of nerves and ganglia. The **nerves** are cables of bundles of nerve fibres (axon and dendron fibres) while ganglion is the concentration of cell bodies of neurons with in peripheral nervous system. Nerves may be **sensory nerves** (contains sensory neurons), **Motor nerves** (contain motor neurons) and **mixed nerves** (contains both sensory and motor nerves). There are two types of nerves on the basis of their origin *i.e.* spinal nerves and cranial nerves.

Spinal Nerves

In human thirty-one pairs spinal nerves, all are mixed. Each serves those regions of the body where it is located, Cervical, 8; Thoracic, 12; Lumber, 05; sacral, 05; coccygeal, 01. Each nerve has a dorsal root, contains sensory fibres and ventral root contains motor fibres. Both of these roots join just before a spinal nerve leave the vertebral column.

Cranial Nerves

These nerves are also called **cerebral nerves**. There are 12 pairs of cranial nerves arising from or lead to the brain. The cerebral nerves functionally may be sensory (three pair I, II VIII), motor (five pairs, III, IV, VI, XI, XII) and mixed in nature (four pair V, VII, IX and X). These are mostly concerned with head, neck and facial regions of the body, only 10^{th} cranial nerves, named **vagus** have branches to the pharynx, larynx and most internal organs.

The peripheral nervous system functionally subdivided into the somatic and autonomic nervous system.

Somatic Nervous System (SNS)

This subdivision controls voluntary movements which are consciously controlled, involving skeletal muscles except reflex action of skeletal muscles.

Autonomic Nervous System (ANS)

This subdivision controls involuntary responses (automatic and subconscious), consists of both sensory neurons and motor neurons that runs between central nervous system and many viscera like lungs, heart and glands. Autonomic nervous system also controls the contraction of cardiac and smooth muscles.

The motor neurons of autonomic nervous system are divided into sympathetic nervous system and parasympathetic nervous. The differences between these two system are explained in the Table 17.1. (Fig.17.16)

Table 17.1: Differences between Sympathetic and Parasympathetic Nervous System

Sympathetic Nervous System	Parasympathetic Nervous System
• It prepares the body for emergency situations and associated with "flight and flight". Increase metabolism to avoid danger.	• It promotes all internal responses which are concerned with the rest situation, and maintain body homeostasis, *i.e.* returns body functions to normal position.
• Accelerates the heart beat from set point, rise BP.	• Retards heart beat that is maintain at set point and lowering of BP.
• Dilates Pupils	• Contracts Pupils.
• Inhibits digestion of food	• Increases digestion of food.
• Most preganglionic fibre (nerves) arise from the middle portion of the spinal cord and almost immediately terminate in ganglia that lie near the spinal cord.	• A few cranial nerves, including the vagus nerve, together with fibres that arise from the sacral (bottom) portion of the spinal cord.
• Preganglionic fibres are short and postganglionic long.	• Preganglionic fibres are long and postganglionic short.

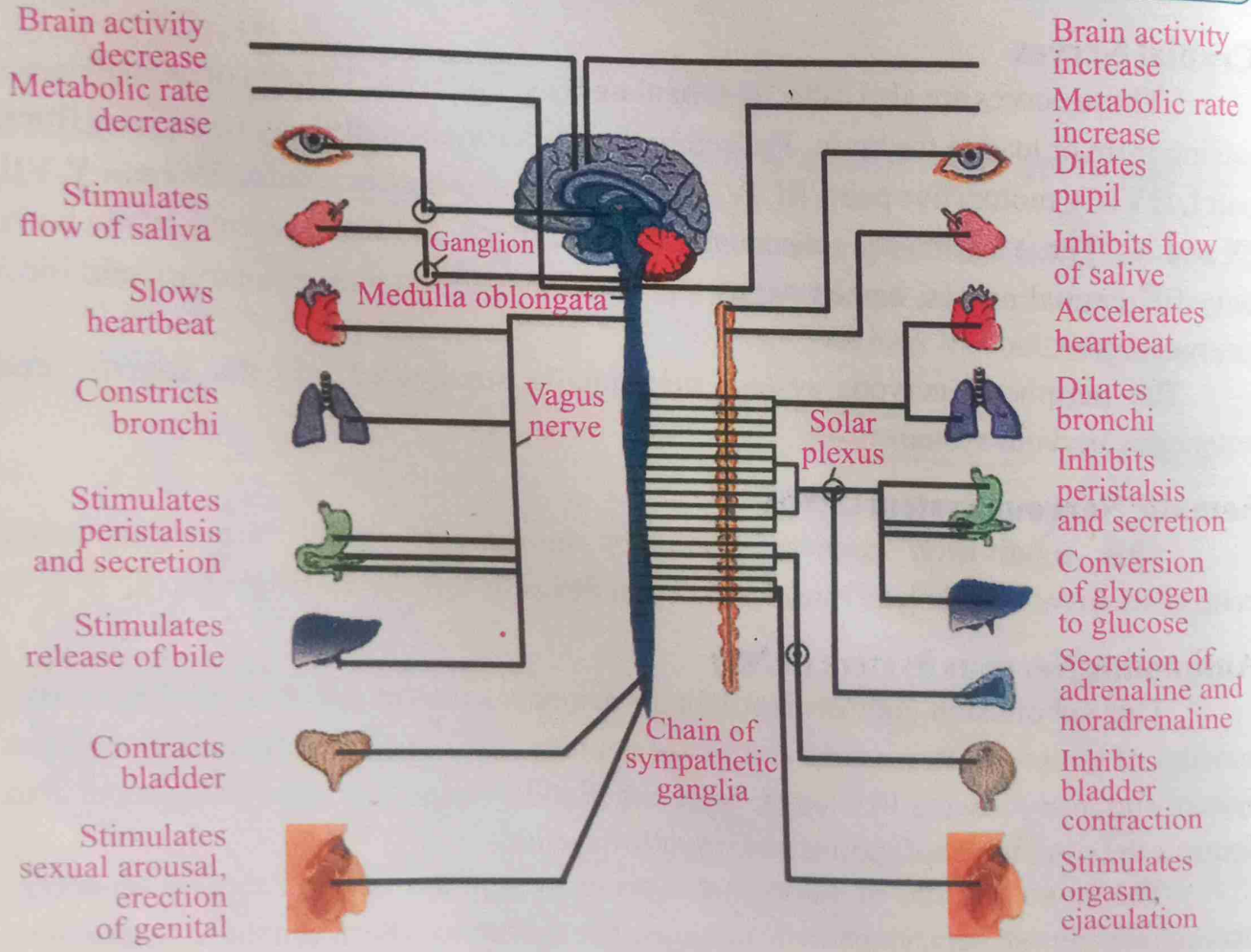


Fig. 17.16: Parasympathetic and Sympathetic Nervous System

17.5.5 Structure and Functioning of Receptors of Smell, Taste, Touch and Pain

1) Smell or Olfactory Receptors

The receptors, which are stimulated by chemicals are called smell or olfactory receptors. In human it is not as much developed or important as vision and hearing. Although in most predators sense of smell is highly developed and important to detect preys. These receptors are located in the upper part of the nasal cavity, which are neurons. The neurons are surrounded by ciliated columnar epithelial cells. Chemicals that stimulate the olfactory receptors enter the nasal cavity as gases, which dissolve in watery fluids that surround the cilia before they can be detected. The axons of neurons carry the smell impulses to the olfactory bulb of fore brain for appropriate responses. (Fig.17.17)

Interesting Information

There are about 1,000 different types of receptor protein on receptor neurons, each is sensitive to different odors.

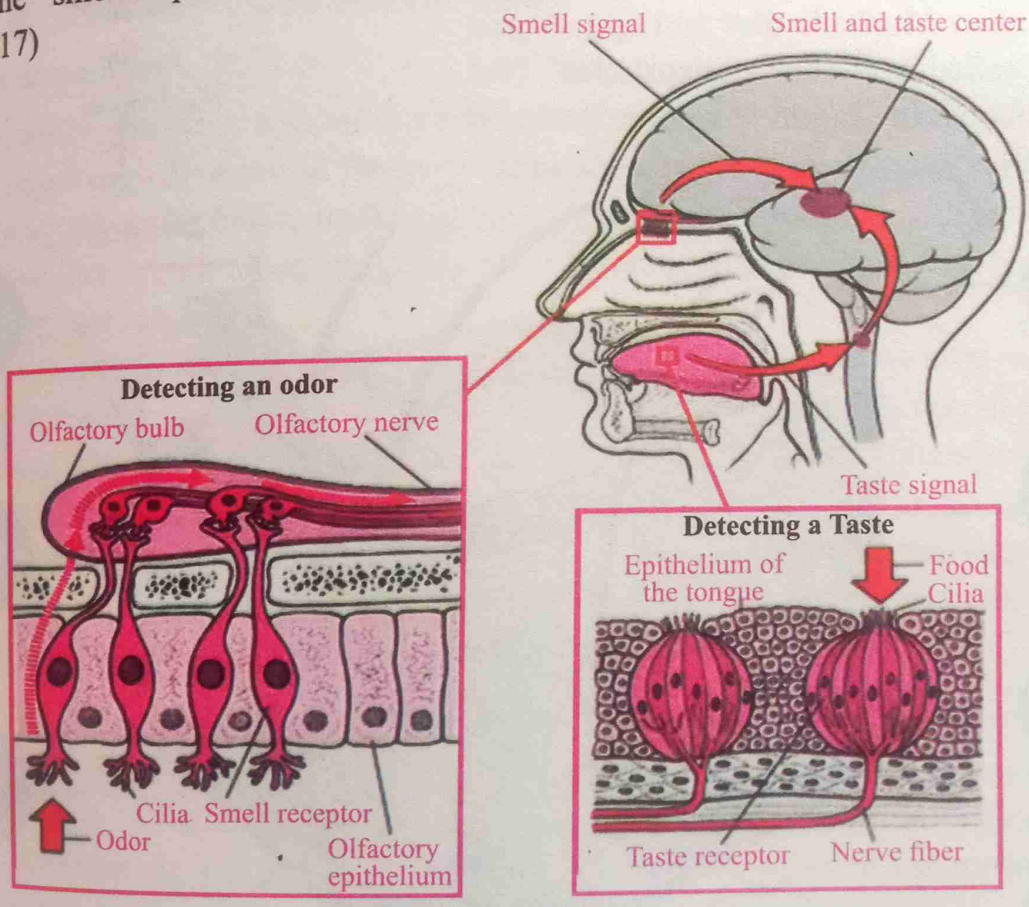


Fig. 17.17: Olfactory and Gustatory Receptors

2) Taste Receptors (Gustation)

These receptors are located on the throat and mouth especially in the upper surface

of tongue as many raised structure called **papillae or taste buds**. Each taste bud has a pore through which fluid in the mouth contact the surface of receptor cells.

There are thousands of taste buds which perceived tastes, all are combination of four primary sensations; **sweet** (elicited by sucrose, glucose and other simple sugars), **sour** (acids), **salty** (NaCl and other salts) and **bitter** (alkaloids and other potentially toxic plant substances). (Fig.17.18)

3) Touch (Tactile Receptor)

There are two touch receptors (also called **mechanoreceptors**) disc-shaped dendrite endings called **Merkel's disc** and egg shaped receptors called **Meissner's corpuscles'**. (the word corpuscle mean "Little body"). (Fig.17.19)

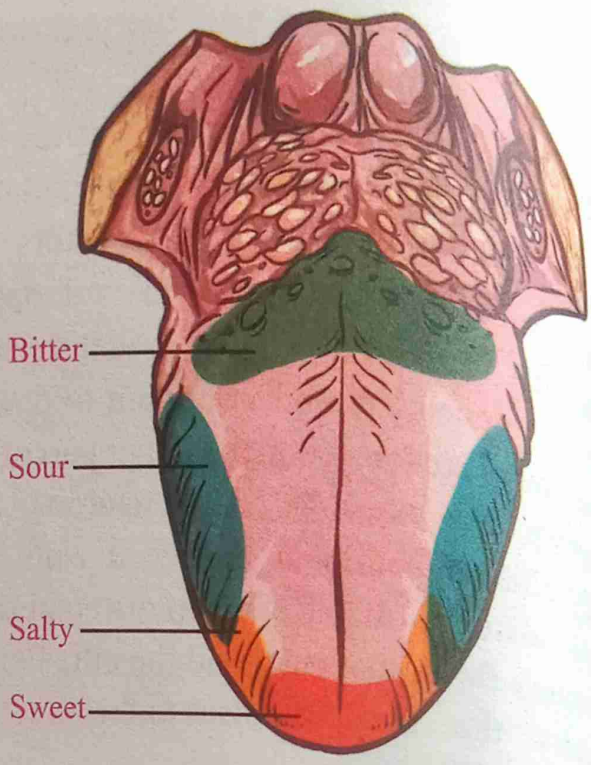


Fig. 17.18: Four Receptor on the Tongue

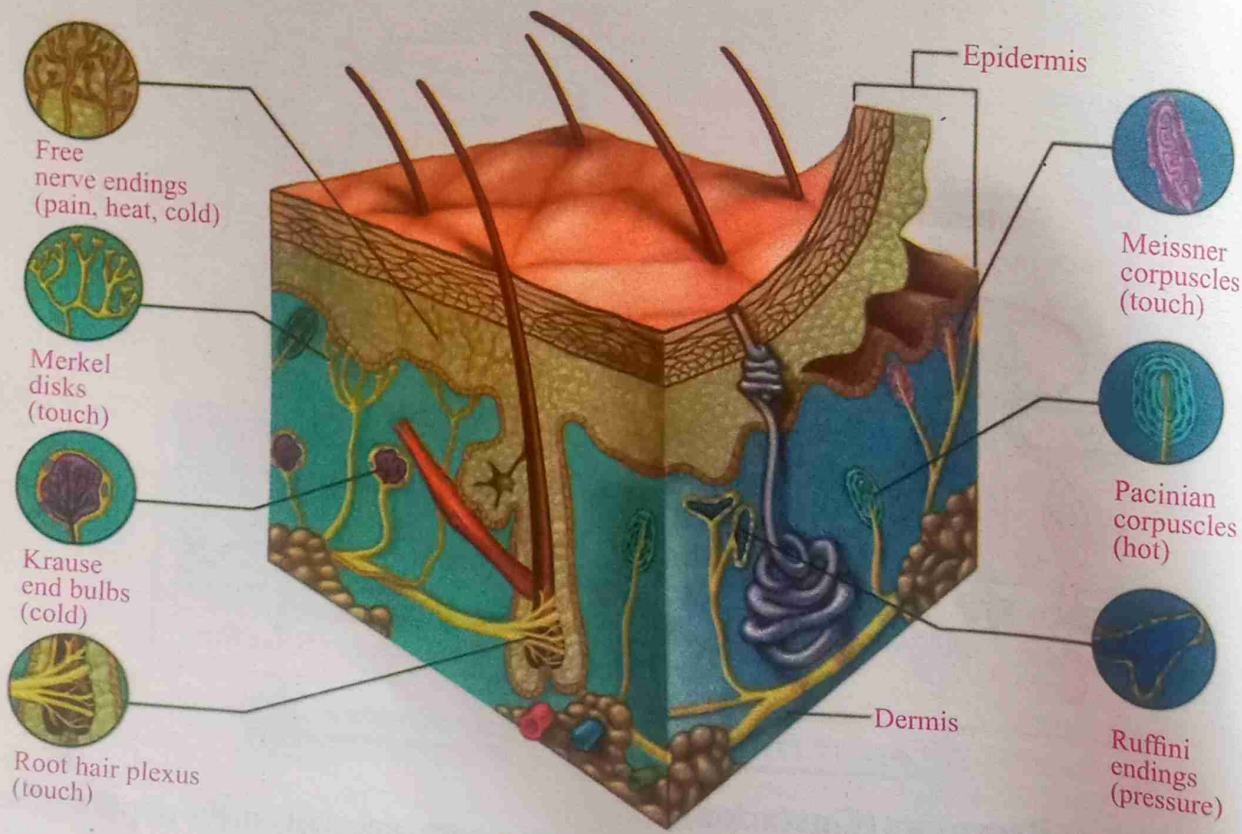


Fig. 17.19: T.S Skin

Both these receptors are widely distributed in the skin but are most numerous in the hands (finger tips), feet, and eyelids, tip of the tongue, lips, nipples, clitoris and tip of the penis. In addition, free nerve endings wrap around the roots of hairs, detect stimulus like wind or an insects that moves body hair.

Pressure receptors called **pacinian corpuscles** are placed deeper with in skin.

1) Pain Receptors (Nociceptors)

There are three types of pain receptors, *i.e.* **cutaneous** (skin), **somatic** (Joints and bones), and **visceral** (all body organs except brain). These receptors are naked dendrites that respond to chemicals released from injured tissues or excess stimuli of pressure and heat.

2) Thermorceptors

Which are encapsulated nerve endings located in the dermis of skin (for hot **Ruffini ending** and for cold **Krause end bulbs**).

17.6 Effects of Drugs on Nervous Coordination

Broadly speaking, **a drug** is a substance introduced into the body to provoke a specific physiological response. Some drugs help a person cope with illness or emotional stress. Other act on the brain, artificially fanning pleasure associated with sex and other self-grafting behaviors. Many drugs are habit-forming. **Habituation** and tolerance are sign of **drug addiction**.

A **narcotic** is a group of substances, bind to certain pain killing sites in the brain thus stop the perception of brain. Their constant use blocks the production of endorphin (natural pain killer hormone secreted from anterior pituitary gland). Thus narcotic acts as an agent which interacts with the normal nervous activity.

The **side effect of narcotics** is change in mood, drowsiness, nausea, vomiting, **euphoria** (an exaggerated feeling of wellbeing), *etc*. Some common narcotic drugs are discussed here.

Introduction

Nervous system is not capable to innervate all the cells of the body thus another coordinating system is needed. Endocrine system fulfils this gap by chemical coordination.

A **hormone** is a "chemical messenger", secreted by an endocrine gland. Traditionally hormones have been described by scientists as the chemical products travel within the bloodstream to all parts of the body, causing an effect on specific cells or target

organs. It also affects exocrine glands or individual cell or tissue that secrete chemical substances. The glands that secrete hormones, pour directly into the blood stream are called **endocrine glands** or **ductless glands.** The glands which secrete other substances such as digestive enzymes, milk, sweat, bile and route their secretions to specific destinations by means of ducts are called **exocrine glands or ducted glands.**

18.1 Hormones- The Chemical Messengers

Path of chemical message (Hormone)

Hormones are "chemical messengers", secreted by cells that affect other cells. Hormones that travel within the blood stream and affect cells in another part of the body are known as "**endocrine hormones**". While those hormones that do not travel within the blood stream but only affect cells lying near the secretary cells are known as **"local hormones"** e.g., serotonin, prostaglandin, gastrointestinal hormones etc.

Role of Hormones

Hormones are small soluble organic molecules which are effective in low concentration and affect at a site where specific receptors are present therefore, hormone is either increase or decrease or modify the secretion of other glands. They also increase or decrease a body structure.

18.1.1 Chemical Nature of Hormones

Chemically, there are three basic types of hormones, which are:

1. Steroid
2. Amino acids or their derivatives, proteins and glycoproteins.
3. Few belong to the fatty acids e.g., prostaglandin

Steroid hormones are derivatives of cholesterol and secreted by cortex of adrenal gland (cortisol and aldosterone), testes (androgen), ovaries and placenta (estrogen and progesterone).

Amino acid derivatives are of two groups. The epinephrine and nor-epinephrine are secreted from adrenal gland, thyroxin and tri-iodothyronine (T_3), secreted by thyroid glands. All these are derivatives of tyrosine amino acid.

Polypeptide hormones are oxytocin, vasopressin, adrenocorticotrophic hormone, calcitonin, parathormone, melanocyte stimulating hormones.

Proteinaceous Hormones include somatotophic hormone, (STH) and insulin.

Pheromones

They are hormone-like chemical messengers but removed outside they body. These are small, volatile chemicals that function in communication among animals and fungi. They act by influencing the physiology and behaviour of the receiving individuals.

Extra Information

Oxytocin and antidiuretic hormones are peptide of only nine amino acids.

Glycoprotein hormones are Follicle Stimulating Hormone (FSH), Luteinizing Hormone (LH), human chorionic gonadotropin (hCG) and Thyroid stimulating hormone (TSH).

18.1.2 Mode of Hormone Action

There are two modes of action of hormones.

1. Fixed Membrane Receptor Mechanism

The peptide and protein hormones cannot pass through cell's plasma membrane because they are water soluble. Thus attached with the receptors on the plasma membrane of target cell and then start a series of steps in the cell. Adenylate cyclase is an enzyme of plasma membrane, which involved in ATP meta-bolism as catalyst, the transfo-rmation of ATP into second messenger, the **Cyclic Adenosine Monophosphate (cAMP).**

The cAMP triggers various changes in the cell including activation of enzymes, gene activation (another term use to describe this entire process is called **signal transduction**). (Fig.18.1)

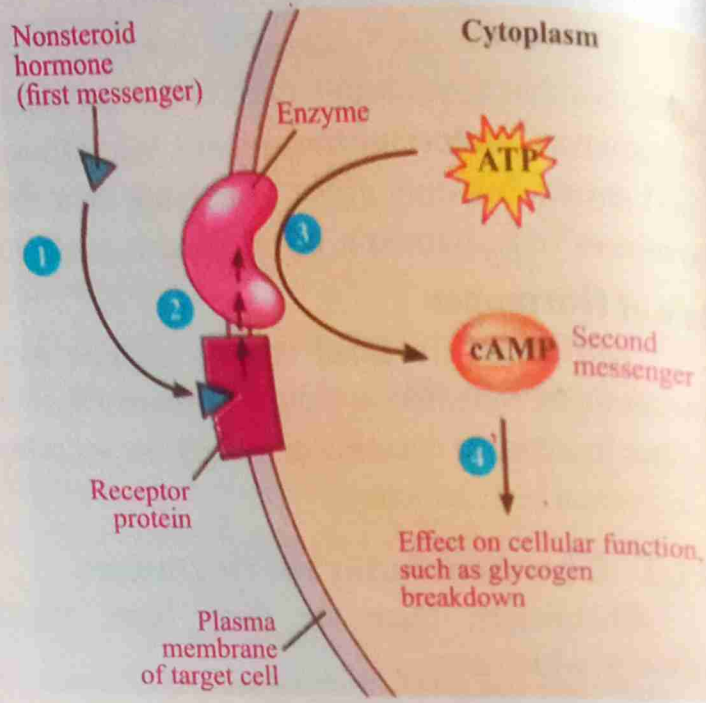


Fig. 18.1: Action of Non-steroid Hormone

2. Mobile Receptor Mechanism

(Gene/signal Modulation)

The steroid and amino acid derivative hormones can easily pass through plasma membrane because both are lipid soluble. Their receptors are placed inside target cells i.e., either in cytoplasm or nucleus. These together with target receptors form hormone-receptor complex, which then travel to the particular gene, acting as transcrip-

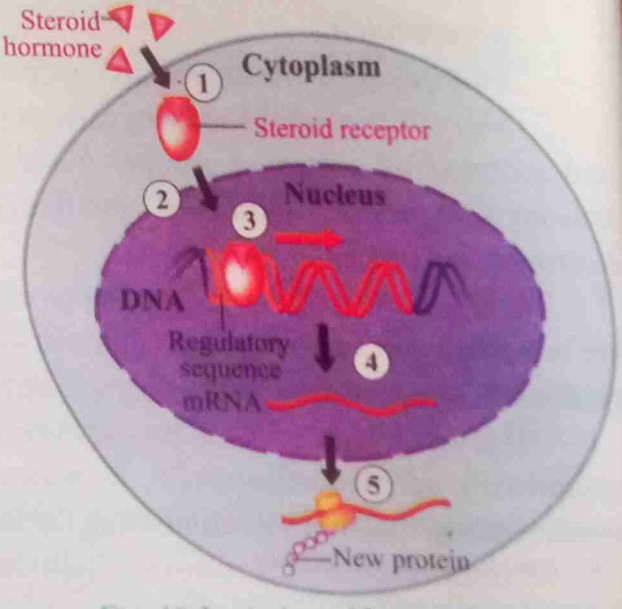


Fig. 18.2: Action of Steroid Hormone

tion factor. The target gene is transcribed into messenger RNA then it is translated into polypeptide (protein) in cytoplasm. Thus the activities of target cells are modified by the alter gene expression. (Fig.18.2)

18.2 Endocrine Glands (System) of Human

Human endocrine system includes about 20 different endocrine glands, some of which are hypothalamus, pineal, pituitary, thyroid, parathyroids thymus, adrenal, pancreatic islets and gonads. (Fig.18.3)

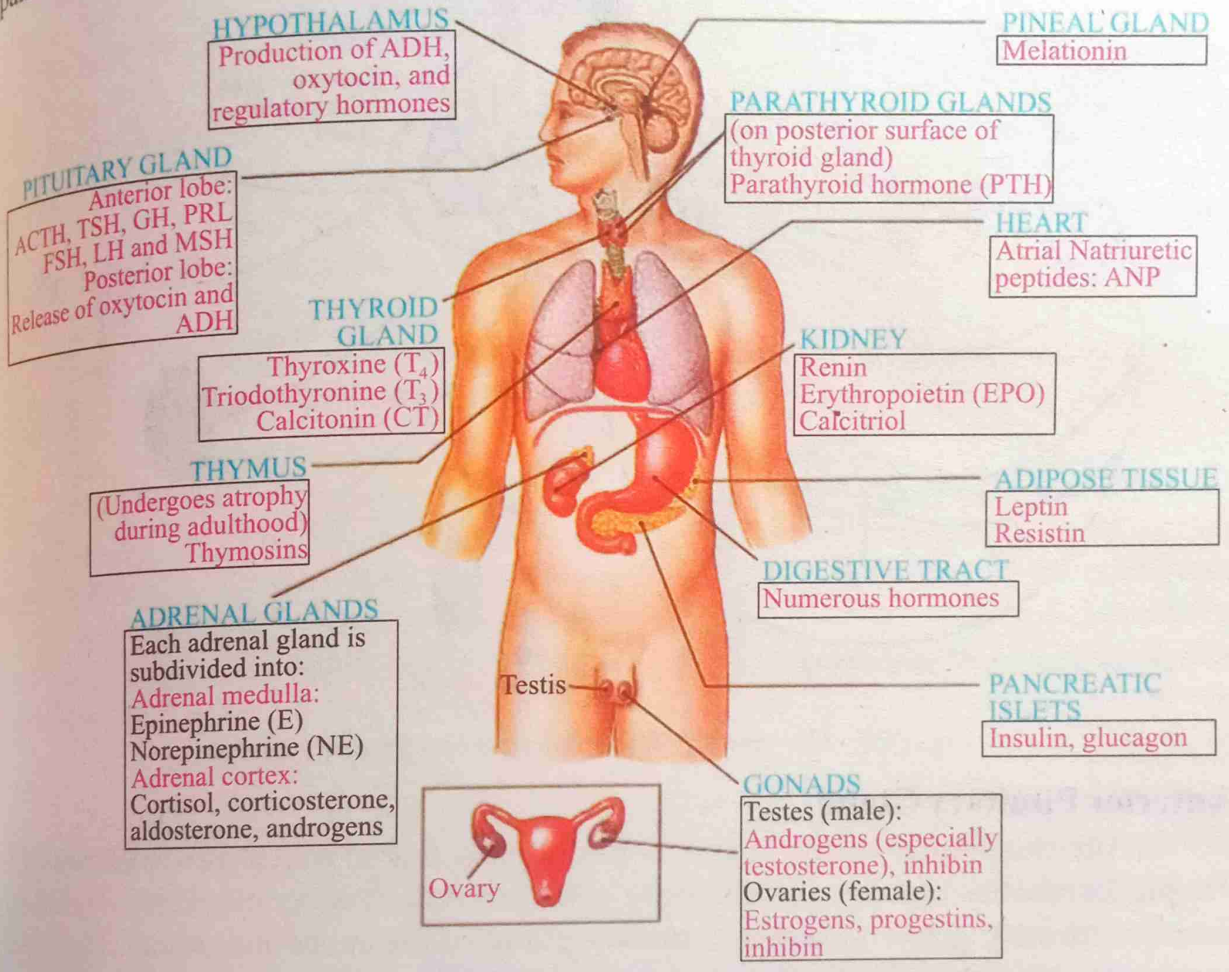


Fig. 18.3: Major Endocrine Glands

18.2.1 Pituitary Gland

Pituitary gland is small pea-sized gland, (about 0.5gram) lies in the brain. It is attached with hypothalamus by a stalk known as **infundibulum**, which is made of blood vessel and the nerve fibres of neurosecretory cells. Pituitary gland is divided into three lobes, the anterior pituitary (**adenohypophysis**), posterior pituitary gland (**neurohypophysis**) and intermediate pituitary (**Median lobe**). (Fig. 18.4)

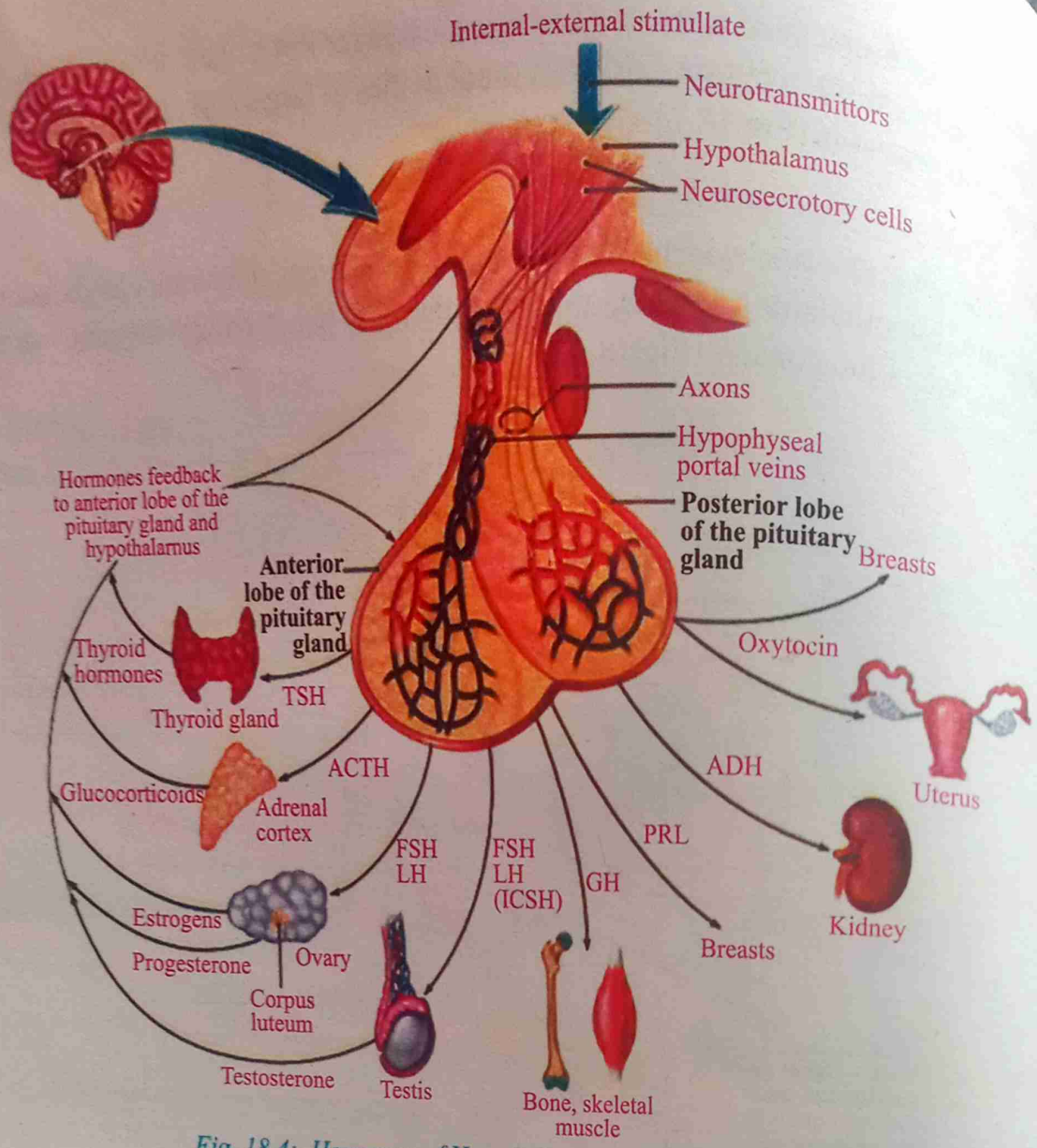


Fig. 18.4: Hormones of Hypothalamus and Pituitary Glands

Anterior Pituitary Gland

Anterior pituitary gland secretes six hormones, four of which are tropic hormones. **Tropic hormones** regulate the secretory action of other endocrine glands. Therefore, anterior pituitary gland is known as **master gland** of the endocrine system. The tropic hormones are thyroid stimulating hormone **(TSH)**, adrenocorticotropic hormone **(ACTH)**, follicles stimulating hormone **(FSH)** and luteinizing hormone **(LH)**. Other two anterior pituitary hormones are called **primary hormones**, such as growth hormone **(GH)** and prolactin **(PRL)**, these directly affect body structure or exocrine gland.

i) Growth Hormone (GH) or Somatotrophic Hormone (STH)

Its stimulating factor is **somatotropin releasing factor (SRF or GHRF),** which is secreted from hypothalamus throughout life and inhibited by hypothalamic **somatostatin** (Inhibitor Hormone).

Growth hormone has a direct effect on growth of the body, skeleton and skeletal muscle. It also stimulates cell growth and cell division, increases movement of amino acids to the cells i.e., helps in protein synthesis.

Disorders due to over secretion of GH in **early life** is called **gigantism.** It causes extraordinary elongation of bones and person becomes giant.

While in **adulthood**, the bones grow in thickness, thus enlargement of hand, feet, skull, nose and Jaw bones occur. This condition is called **acromegaly**.

Deficiency of GH leads to **pituitary dwarfism**, the development is much slower than normal. The individual has short stature, but the development of brain and Intelligence Quotient (IQ) is not affected.

ii) Thyroid Stimulating Hormone (TSH)

TSH controls the secretion and development of thyroid gland. Its secretion depends on the level of thyroxin in the blood. Hypothalamus detects the level of thyroxin, if it is less then hypothalamus secretes **thyroid releasing factor (TRF) or thyrotropin**, which in turn stimulates pituitary gland to release TSH that affects the activity of thyroid gland.

Low TSH level may be harmful for health, heart disease and osteoporosis may occur. While high TSH level in blood indicates hypothyroidism.

iii) Adrenocorticotropic Hormone (ACTH)

It acts on adrenal cortex and stimulates the secretion of **corticosteroids** (cortisone and aldosterone). The secretion of ACTH is stimulated by **adrenocorticotropic releasing factor (CRF)** from hypothalamus as a result of stress e.g., pain, cold, fear, stress, infection and pregnancy. Cushing disease is caused by a pituitary gland tumour, that over secretes the hormone ACTH, thus over stimulate adrenal cortex to secrete cortical production.

iv) Gonadotropins

Gonads are the male and female sex organs (testes/ovaries). The gonadotropins are hormones that affect these sex organs, thus considered endocrine glands because they secrete sex hormones i.e., follicle stimulating hormone and Luteinizing hormones.

Follicle Stimulating Hormone (FSH)

In human females, FSH targets the ovary and triggers the maturation of one egg (sometime more than one egg) per month. In addition, it stimulates cells in the ovaries to secrete female sex hormones called estrogen.

In males, FSH targets the testes and triggers the production of sperms. The secretion of FSH is stimulated by gonadotropin releasing hormone (GnRH) from the hypothalamus.

Luteinizing Hormone (LH)

Its secretion is also controlled by gonadotropin releasing hormone (GnRH). **In**

females a surge of LH near the middle of menstrual cycle stimulates the release of an egg from grafian follicle of ovary. In addition, LH triggers the development of cells within the rupture follicle to form a glandular structure called **corpusluteum** which secretes a hormone known as **progesterone** (to prepare uterus for coming embryo). LH is also responsible for multiple births. **In male,** LH is also known as **Interstial Cell Stimulating Hormone** (ICSH). It promotes production of the male sex hormone **testosterone**.

Low secretion of both FSH and LH leads to delay sexual maturation. The GnRH deficiency may be by birth or acquired.

Prolactin Hormone (PRL)

It works in conjunction with estrogen, progesterone and other hormones. It causes enlargement of the mammary glands and prepare them for the production of milk (lactation) after birth. It stimulates mothers to care their young ones. During the menstrual cycle, milk is not produced or secreted because prolactin level in the blood is very low. Its secretion is inhibited by **Prolactin Inhibiting Factor (PIF)** from hypothalamus.

Posterior Pituitary Lobe (Gland)

The posterior lobe of the pituitary is nonglandular, it stores and releases two hormones that are produced by the hypothalamus. These are **Antidiuretic Hormone (ADH)** and **Oxytocin**.

Interesting Information

Lack of antidiuretic hormone causes "diabe-tes insipidus". As a result, there is the production of large quantity of watery urine and person feels great thirst and dehydrated.

i) Antidiuretic hormone (ADH)

It helps to regulate volume of the blood by regulating the amount of water reabsorbed by the kidneys. For example, osmoreceptors in the hypothalamus can detect a low blood volume by detecting when the solute concentration of the blood is high, then the neurosecretory cells of hypothalamus make ADH, which is transported within axon to the posterior pituitary, then releases into the blood stream. ADH binds to target cells in the collecting ducts of the nephrons of the kidneys, increasing their permeability for water reabsorption, thus urine becomes concentrated. ADH also acts on the smooth muscles surrounding arterioles, an action that helps to raise the blood pressure. Alcohol suppresses ADH release that is why excessive drinking leads to the production of excessive quantities of urine and eventually to dehydration.

ii) Oxytocin

It is also produced in hypothalamus and transported within axons to posterior pituitary for secretion. **In women,** it is secreted **during birth** process, triggered by stretching of the cervix of uterus at the beginning of the birth process, oxytocin binds to target cells of the uterus, increasing the contraction which is already taking place. It is

also used artificially to induce labor. In **lactating women**, suckling causes the release of oxytocin, which targets muscle cells around the duct of mammary glands, thus promote milk ejection. **In male,** it helps to eject semen during copulation.

Median Lobe of Pituitary

It is smallest in human, made of thin layer of cells between anterior and posterior pituitary gland. It secretes **Melanocytes Stimulating Hormone (MSH).** The MSH releases due to influence of external light and more secretion during pregnancy. It stimulates melanocytes in skin and hair to produce brown pigment, the **melanin** that darkens the skin.

18.2.2 Hypothalamus

Hypothalamus is a part of fore brain, which is both nervous and endocrine. Thus it receives many sensory stimuli of the nervous system and are converted into hormonal responses. It is master control centre of endocrine system because it monitors metabolites and hormonal level in the blood. It directly controls the pituitary gland. Hypothalamus has nerve cell clusters that produce and secrete many types of hormones. One of these centres produces and secretes a variety of releasing (Tropic) and inhibiting hormone or factor. Thus act as regulatory hormones, which regulate the synthesis and secretion of other endocrine glands.

Extra Information

1. The suckling of the infants triggers the production of great amount of oxytocin, that aids in nursing process and contracts the uterus to its normal size.
2. Over secretion of oxytocin during child birth may cause rupture of uterine wall.
3. Under secretion of oxytocin inhibits normal labor process.

It has another nerve cluster which synthesizes antidiuretic hormone and oxytocin hormone, then transported and stored in posterior pituitary gland. (Table.18.1)

Table 18.1: The Function of Hypothalamus and Response with Pituitary Gland

S.No.	Hormone From Hypothalamus	Anterior Pituitary Response
i)	Growth hormone releasing factors (GHRF).	Secretion of growth hormone (GH).
ii)	Somatostatin.	Inhibits growth hormone (GH).
iii)	Gonadotrophin releasing hormone (GnRH).	Secretion of FSH, LH and ICSH.
iv)	Adrenocorticotropic releasing factor (CRF or ACRF).	Secretion of adrenocorticotropic hormone (ACTH).
v)	Prolactin inhibiting factor (PIF).	Stop secretion of prolactin.
vi)	Thyrotropin releasing factor (TRF).	Secretion of thyroid stimulating hormone (TSH).
vii)	Secretes oxytocin and ADH.	Store these hormones in posterior pituitary lobe.

18.2.3 Thyroid Gland

Thyroid gland is located at the base of neck, attached to trachea below the larynx. It is bilobed structure, butterfly-shaped and both lobes are connected by a bridge of thyroid tissue known as **isthmus**. Thyroid gland is made of spherical cells filled with three types of hormones. (Fig.18.5)

1. Tri-iodothyronine or T3 (about 10% but four time more potent than T4). It is more active in mammals .
2. Tetra-iodothyronine or T4 (about 90% thus major hormone also called thyroxin).
3. Calcitonin hormone.

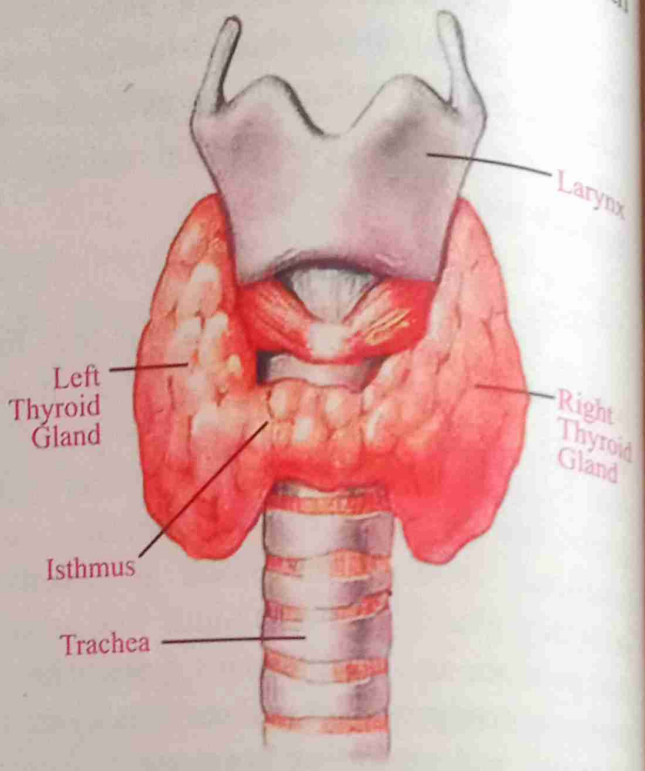


Fig. 18.5: Thyroid Gland

Both T3 and T4 have similar structure and function, but T3 has three iodine while T4 has four iodine. The duration of action duration of T4 is four times more than T3. Their secretion is controlled by TSH from anterior pituitary gland. The T3 and T4 act on **Basal Metabolic Rate (BMR)** by stimulating the breakdown of glucose, release of heat, generation of ATP and synthesis of cholesterol in the liver.

Thyroxin, in conjunction with Growth Hormone (GH) acts on physical growth and mental development. Thus causing them to differentiate between foetus and infant. It also promotes normal motility of the gastrointestinal tract.

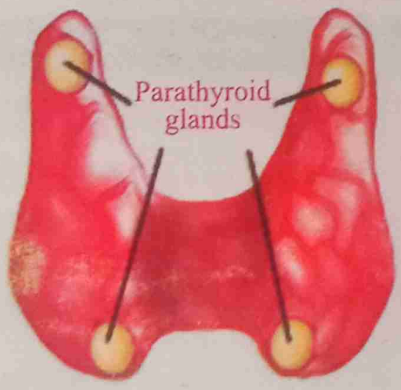


Fig. 18.6: Thyroid Gland (Back view) and Parathyroid Gland

Extra Information

Thyroxin helps in metamorphosis of tadpole to adult frog. If its concentration is less, then tadpole does not metamorphose to adult frog instead remains a large size tadpole.

Effect of Over secretion of T3 and T4 (Hyperthyroidism)

The excess secretion of thyroxin causes a condition known as **grave's disease.**

This disease causes **exophthalmic goitre** (bulging of the eye ball), which is a classical symptom of hyperthyroidism. If the patient's basal metabolic rate (BMR) increases, this can lead to cardiac failure, profuse perspiration and weight loss. It is an autoimmune disease, the blood serum of patient has abnormal antibodies to mimic TSH and continuously stimulates thyroxin release.

Effect of Under Secretion (Hypothyroidism)

The less secretion of T3 and T4 (thyroxin) causes **Cretinism, Goitre** and **Myxoedema**. Hypothyroidism may be due to absence of iodine or failure of enzyme system, which is involved in the production of thyroid hormone or due to lack of TSH.

Cretinism: In infant, less secretion of thyroxin causes dwarf condition known as **cretinism**. It is characterized by stunted growth, mental retardation, coarse facial features, coarse scanty hair, retarded sexual development.

Myxoedema: (Mean mucous swelling) In adult, low secretion of thyroxin causes myxoedema. The patient has lower metabolic rate, thickness of skin of hands, brittleness of hair and nail, intolerance to cold, mental lethargy, weight gain, low pulse rate and low body temperature (Myxoedema also called **endemic** or **colloidal goitre**).

Goitre: The deficiency of iodine causes enlargement of thyroid gland known as goitre. It is more common in mountainous areas where iodine is less in the soil or water. (Thus table salt with iodine is recommended). Thyroid gland works hard to produce sufficient amount of thyroxin. Goitre may lead to lying down of excess of fat and weight increases.

Calcitonin hormone

Thyroid gland also secretes calcitonin hormone, which plays an important role in controlling extra level of calcium ions. If calcium level rises in the blood, then it promotes the deposition of calcium in bone or prevent their reabsorption from nephrons of kidneys. It also inhibits calcium absorption by the intestine.

The **over** and **under secretion of calcitonin** leads to disturbance of calcium metabolism. Thus affects skeletal muscle (become weakened), nervous system (impulses become irregular) and blood calcium composition is disturbed, this leads to massive kidney stone.

18.2.4 Parathyroid Glands

Parathyroid glands are very small glands, which are embedded to the posterior surface of thyroid gland. They are four in number and oval in shape. Parathyroid secretes a hormone known as **parathormone**, which regulates level of calcium and phosphorous in the blood and influence gene activation. Lower calcium level of blood stimulates the parathyroid directly to increase parathormone secretion. It absorbs calcium from intestine and kidney while high level suppresses its production. (Fig.18.6)

Deficiency of Parathormone decreases blood calcium level which result excitability in nerves, muscles and convulsion. The nerves become very sensitive to stimuli, spasm and even death may occur, in case of severe deficiency.

Over Secretion of parathormone causes increase of calcium level in the blood, low phosphate concentration. It causes weakness of skeleton similar to rickets. Nerve and muscle do not response well to stimuli (movement of Ca^{++} to extracellular fluids). It increases reabsorption of Ca^{++} by the kidneys, causes massive kidney stone formation. These both conditions may be fatal. The removal of these glands causes death.

18.2.5 Pancreas: (Islets of Langerhans's)

Pancreas has both exocrine and endocrine tissues. **Exocrine tissues** secrete pancreatic juices containing digestive enzymes. The **pancreatic acinar cells** are their functional units. The endocrine clusters of cell known as **islets of Langerhans's** secrete two main types of hormones by two major types of cell i.e., **beta cells about (60%) secretes insulin** and **alpha cells about (25%) secrete glucagon hormones**, both hormones are protein in nature. The secretion of hormones is controlled by pituitary hormones STH and ACTH and responds directly to blood glucose level. (Fig.18.7)

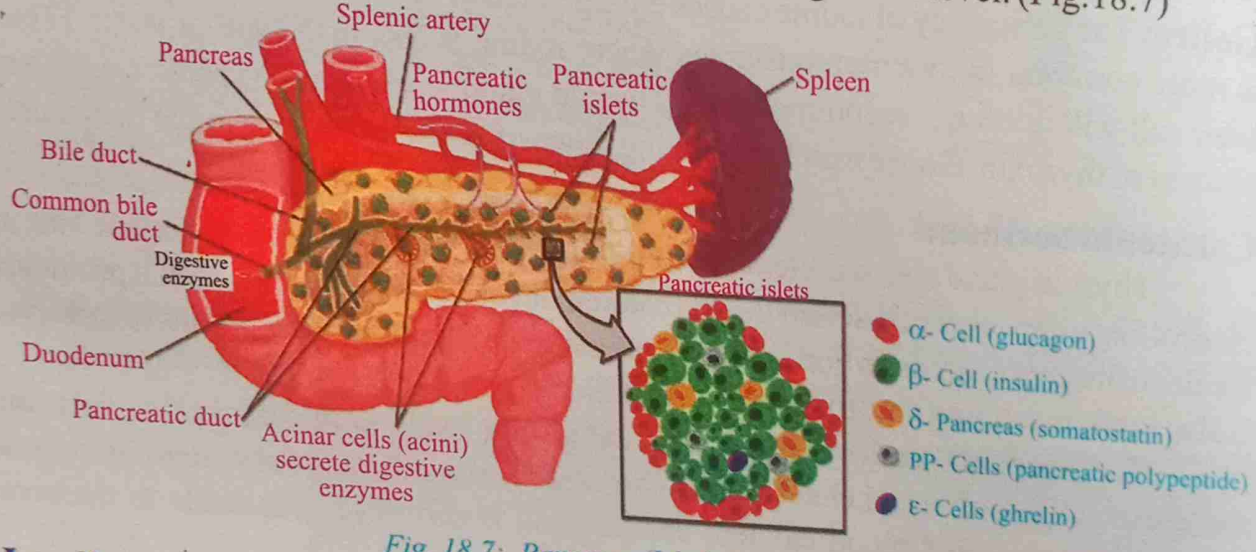


Fig. 18.7: Pancreas (Islet's Langerhans)

Insulin

The beta cells of pancreas secrete a hormone called insulin made of 51 amino acids. It is secreted when blood sugar level rises, such as after meal.

Functions of Insulin

1. It facilitates glucose transport across plasma membrane.
2. It stimulates uptake of glucose by liver, muscles and adipose tissue (fat storing cells).
3. Promotes synthesis of proteins and fats by transferring glucose.

3. Inhibits gluconeogenesis (conversion of amino acids and fats into glucose). Thus lowers blood glucose level.
4. It increases **glycogenesis** (in this process insulin converts glucose into glycogen).
5.

Glucagon

1. **Alpha pancreatic cells** secrete glucagon, made of 29 amino acids.
2. When blood glucose level decreases, glucagon converts glycogen, amino acids and fatty acids into glucose.
3. It is antagonistic to insulin.
4. Sympathetic nervous system stimulates its production.
5. It increases **Glucogenesis,** which is the process of conversion of glycogen into glucose, and, **Gluconeogenesis,** the breakdown of protein, fats and lactic acids into glucose.

Disorders due to insulin deficiency

The deficiency of insulin may lead to a common metabolic disease, called **diabetes mellitus**. It causes hyperglycaemia.

Symptoms of Hyperglycaemia

1. Sugar is excreted in urine.
2. Frequent urine.
3. Abnormal thrust.
4. Rapid weight loss and weakness.
5. Drowsiness and fatigue.
6. Dehydration

Disorders due to excess of Insulin

It causes **hypoglycaemia**.

The glucose utilization increases, in turn blood fat level gets high, which upset nerve/ muscles actions.

Other types of endocrine cells in pancreas

There are three other types of endocrine cells in pancreas (about 15%) which secrete three types of hormones.

i) **Somatostatin:** It inhibits the release of gastrointestinal hormones.

ii) **Pancreatic polypeptide,** self-regulates the pancreatic secretion activities and affects the hepatic glycogen level.

iii) **Glycine act as neurotransmitter**, its deficiency may lead to type-II diabetes, increases insulin receptor in people without diabetes. It is used as supplement by type-II diabetes patients.

18.2.6 Adrenal Gland: (ad; beside, renal; kidney)

These are located on the top of each kidney, thus two in number and each with two distinct regions. **Adrenal cortex** is outer reddish brown portion. **Adrenal medulla** is inner greyish portion. Both are under the control of hypothalamus, which secretes ACTH releasing factor that stimulates anterior pituitary, which in turn stimulates the adrenal cortex. (Fig.18.8)

Hormones of Adrenal Medulla

Adrenal medulla consists of modified ganglionic sympathetic neurons, which secrete two important hormones known as **adrenaline (epinephrine)** and **nor-adrenaline (nor-epinephrine)**. Both prepare the body for stress and emergency situation *i.e.* sympathetic system. These stimulate liver cells to release glucose thus making fuel for cellular energy.

Epinephrine dilates blood vessels in the brain, heart, skeletal muscles, thus increasing alertness to overcome stress and heartbeat, breathing rate and metabolic rate increases.

Nor-epinephrine constricts blood vessels elsewhere i.e., in digestive system and peripheral vasoconstriction. It also sustains blood pressure.

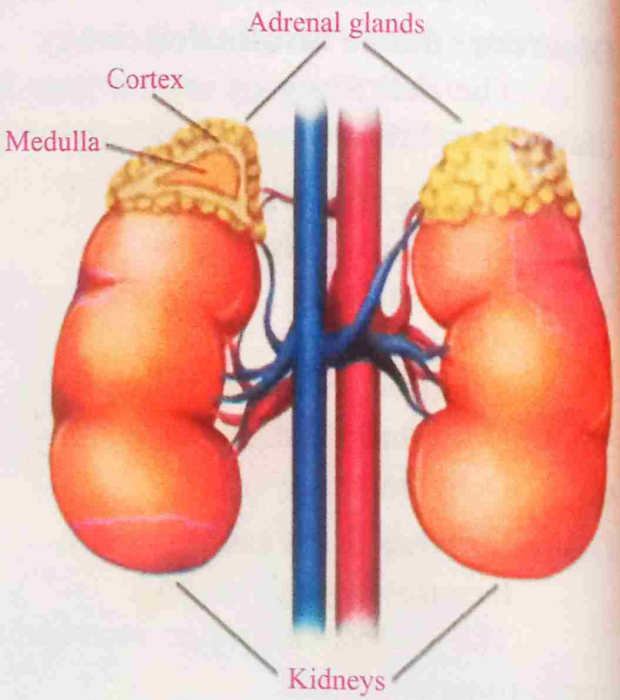


Fig. 18.8: Adrenal Glands on top of Kidneys

Disorders of Medullary Hormones

The over secretion of medullary hormones may cause hypertension and aggressive behavior during routine life while under secretion causes failure to combat with stress situation.

Hormones of Adrenal Cortex

Adrenal cortex remains active all the time, especially after shock or stress situations and infections. It secretes two major hormones.

1. **Glucocorticoids:** It regulates blood glucose level, e.g., cortisone.
2. **Mineralocorticoids:** It regulates the level of minerals in the blood, e.g., aldosterone (Collectively called corticosteroids).

Cortisone

The cortisone is involved in glucose metabolism and is produced during anxiety, fever, and disease.

It promotes the hydrolysis of muscle protein to amino acids, then amino acids to glucose.

It also helps to neutralize the inflammatory responses that leads to the pain and swelling joints in arthritis, etc. It favors metabolism of fatty acids rather than glucose, antagonistic to insulin.

Corticosterone is an example of both glucocorticoid and mineralocorticoid; it increases blood glucose level and regulates mineral ion balance.

Aldosterone promotes renal absorption of sodium and renal excretion of potassium, maintains blood volume and blood pressure.

Adrenal cortex mainly produces aldosterone. The adrenal cortex also produces small amount of male sex hormones called **androgen**, both in male and female. Sometimes tumor in adrenal cortex of female causes excess of androgens production and thus the development of certain male characteristics appear.

Disorders of Cortical Hormones

Two important diseases are caused by abnormal cortical hormones.

1. Addison's disease

This disease occurs by **lower secretion of corticosteroids**, which leads to general metabolic disturbances, low blood sugar level, lethargy and weakness in muscle action, loss of salts and the skin has bronze tone, and cannot overcome stress condition such as cold, heat and stress.

Interesting Information

Epinephrine is sometime given through injection as an emergency treat-ment in cardiac arrest (stopping of heart beat), aphylatic shock (sun stroke) and acute asthma.

2. Cushing's disease

This disease occurs due to **over production of cortisol;** characterized by obesity (fat deposition on the back of neck), muscle wasting, hypertension, diabetes and due to excess protein break down muscle and bones become weak.

18.2.7 Gonads (Sex Organs)

The gonads (ovary and testes) besides gametogenesis, also secrete some important hormones.

Hormones of Ovary

The human female contains two ovaries in the abdominal cavities which secrete two important female sex hormones, estrogen and progesterone.

1. Estrogen

There are three types of estrogen which are almost similar in function (oestrone, oestriole and oestradiole). Estrogen is secreted from ripening follicle (in some species from interstitial cell of ovaries) and placenta under the influence of FSH from anterior

pituitary. These are steroid in nature.

Functions: The estrogen performs following functions.

1. At puberty brings about secondary sexual characters (such as rounded appearance in female due to more fat deposition, large pelvic cavity and wide hips, enlargement of accessory sex organs such as vagina, uterus, oviduct, ovary and external reproductive organs) and high pitch of voice.
2. Conception and maintenance of pregnancy.
3. Help in formation and maturation of egg.
4. At the point during estrous (animals) and menstrual cycle (human) exert a positive feedback which results in a sharp rise in LH output by the pituitary.
5. Healing of uterine wall after menstruation.
6. Prepare uterine wall to secrete proteinaceous substance for embryo.

Disorders due to deficiency of estrogen

In young female, it causes failure to mature sexually. In **adult** causes sterility while **in old women** after menopause, it's deficiency causes osteoporosis.

Disorder due to over secretion

The over secretion may lead to development of fibroids (abnormal growth) in uterus and **polycystic ovary syndrome**.

Interesting Information

Estrogen causes softness and smoothness of skin, therefore, female posse-sses softer skin than male. Estrogen is used in making face cream, soaps and shampoos *etc.*

2. Progesterone

This hormone is produced by the ruptured follicle in response of LH from anterior pituitary. The ruptured follicle becomes corpus luteum. Placenta also secretes progesterone during pregnancy.

Extra Information

Polycystic ovary syndrome is disorder of ovaries, numerous small collection of fluid known as follicles, which may disturb regular release of eggs, thus prolonged, frequent irregular menstrual period and level of male sex hormones increases.

Functions

1. Prepares uterus for implantation of fertilized ovum.
2. Promotes the development of mammary glands during pregnancy.
3. Inhibits further secretion of **FSH** (to prevent any more follicles from ripening).
4. Further thickening and vascularization of the uterus wall.
5. Used in birth control pills (to prevent ovulation).
6. Regulates secretion of gonadotropin from anterior pituitary.

Disorder due to under secretion of progesterone

The less secretion of this hormone during menstrual cycle decreases the chances

of pregnancy and may cause early menstruation. It may lead to the still birth or miscarriage.

Testes: (Male Sex Organs)

The testis in the presence of **FSH** and **ISCH** produce male sex hormones known as androgens, from their interstial cells of Leydig. There are many types of androgen, the most important of which are testosterone and 17 beta-hydroxysteroid dehydrogenase. The functions of these hormones are:

1. In fetus, androgen initiates the development of the sex organs.
2. At puberty brings about secondary sexual characters (beard, moustaches, axillary and pubic hair, voice become low pitch and spermatogenesis) and sex derives.
3. They increase secretion of sebaceous glands, sweat glands and increase sub cutaneous fatty tissue.
4. Increase metabolic activities in general.
5. Inhibit formation of female genital organs in fetus.
6. Increase **Red Blood Cells (RBCs)** production and thickness of bones.

Deficiency of androgens

It causes castration (*i.e.* secondary sexual characters do not appear in male and body looks like an immature female), thus causes male sterility.

18.2.8 Thymus Gland

This lobular endocrine gland is situated at upper part of chest behind sternum. It consists of two lobes that join in front of trachea. It is largest and more active in childhood. It is responsible for the development and differentiation of T-lymphocytes before they leave the thymus. The hormone of this gland is called **thymosin** or **thymin**.

18.2.9 Pineal Gland

It is tiny cone shaped body, located deep between the cerebral hemisphere of brain. It produces the hormone, melatonin.

Function

It is involved in a daily cycle called **circadian rhythm** (Regulated by the eyes of mammals). In many mammals, it regulates the seasonal reproductive cycle, sleep and wake cycle in human. It responds to external conditions of light and darkness as sensed through the eyes.

Role of artificially synthesized steroids in sports and their long-term effects on their users.

Steroids are artificial substances which are developed in order to do the job of testosterone. It can be classified as either anabolic or androgenic. Anabolic functions include those that promote formation of muscles, vertical growth and regulation of weight gain or loss. Androgenic refers to masculine attributes such as agility, strength and endurance. By the help of

these drugs, sportsmen can become bigger, stronger, more agile, and hence more competitive. Artificial steroids uses carry many severe health risks. Major medical problems associated with steroids include a weakened immune system, liver disease, kidney disease, high blood pressure, high cholesterol, increased risk for heart disease, blood clots, strokes, tissue damage and cancer.

18.2.10 Other Endocrine Tissues/cells

Many other hormones are also produced by organs or tissues whose function is not primarily an endocrine one, even neurons also secrete hormones.

Hormones of Gut (Gastro-intestinal Tract)

i) **Gastrin:** The hormone **Gastrin**, produced by the stomach wall, travels in the bloodstream but exerts its effect locally, stimulating the production of gastric juice (pepsinogen and hydrochloric acid). The secretion of gastrin depends on proteinaceous food in stomach when it is partially digested.

ii) **Secretin and Cholecytokinin (CCK):** These two hormones control pancreatic and liver secretion. Both are formed in the cells of duodenal wall, in response to acidic chyme, fatty and proteinaceous food.

Placental hormones

Placenta secretes hormones like progesterone, which maintains pregnancy. It also secretes estrogen, chorionic hormones, relaxin and chorionic gonadotrophin hormones. All of these facilitate in pregnancy and birth.

Hormones secreted from Kidneys

Kidneys produce some hormones such as **erythropoietin** which increases **red blood cell production.** The stimuli such as bleeding or moving to high altitudes (where oxygen is scarcer) trigger release of this hormone.

Kidney also secretes **hormone renin** which constricts arteries and monitors blood pressure, takes corrective action if it drops. It is also called **urotensin** and angiotensin.

Calcitriol: It is also secreted from kidneys and acts on the cells of the intestine to promote the absorption of calcium from the diet.

Hormones of Liver: Liver secretes a group of hormone-like compounds called **prostaglandins**. These provide protective response during infection.

Somatomedins hormone is also secreted from liver that stimulate cell growth and development.

Hormones of Brain: Enkephalins and **endorphins** are two related hormones, produced in the brain. Both bind to pain receptors and so block sensation. The enkelphalins found in thalamus and some parts of spinal cord while endorphins found in pituitary gland, in other parts of brain or distributed throughout nervous system.

Hormone of Heart: The heart secretes **atrial natriuretic hormone**, which increases sodium excretion and lowering blood pressure.

Adipose Tissues: Secretes a hormone **leptin**, which reduces appetite.

18.3 Feedback Mechanism (FBM)

It is a type of interaction in which controlling mechanism is itself controlled by the products of reactions, it is controlling. Different hormones act as a system of check and balance for each other in order to keep homeostasis. In this case two opposing systems are required *i.e.* if there is an excitatory system, there must be an inhibitory system.

18.3.1 Negative Feedback Mechanism

The type of FBM in which increase in production decreases the operation so as to stop the production of products. It stabilizes a system.

Example: If our blood glucose level becomes too high then beta cells in the islets of Langerhans respond to secrete more insulin. The insulin lowers blood glucose by converting glucose into glycogen and making body cell membranes more permeable to glucose. Thus glucose is utilized by cell and surplus glucose is stored in the form of glycogen. (Fig.18.9)

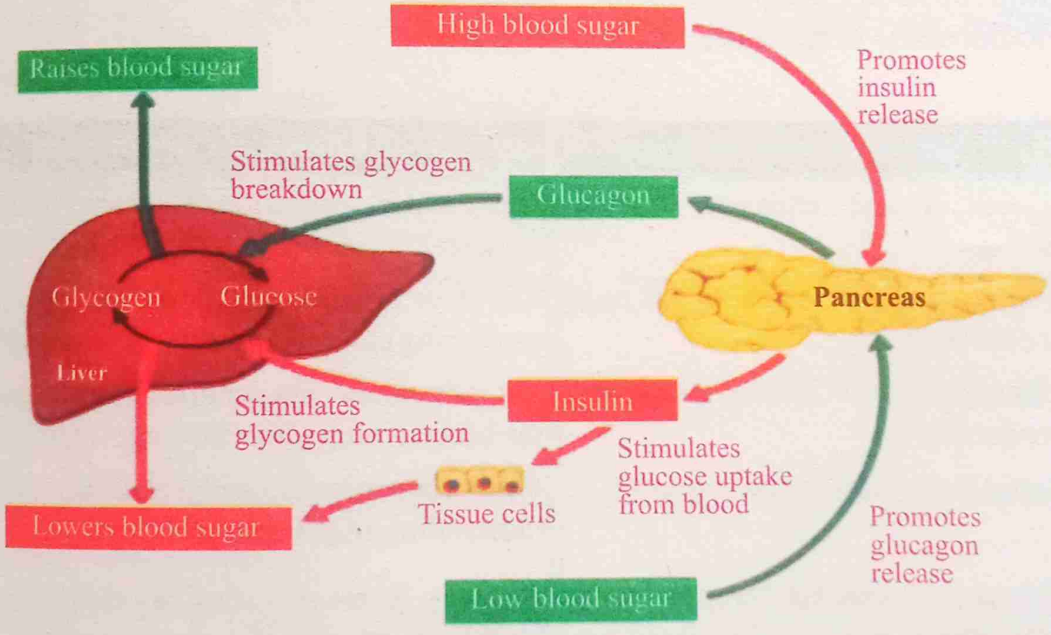


Fig. 18.9: Negative Feedback Mechanism

If the level of blood glucose gets too low, alpha cells in the islets of Langerhans secrete glucagon. It converts glycogen into glucose to raise and maintain blood glucose level. Thus the level of blood glucose is maintained by negative feedback mech-anism.

Negative feedback is most common and self-limiting.

18.3.2 Positive Feedback Mechanism

The type of FBM in which increase in production of a substance increases the operation to produce more products. It speeds up the system rather to stop it, *e.g.* Oxytocin production during labor and suckling by baby. It is rare, explosive and self-reinforcing. (Fig.18.10)

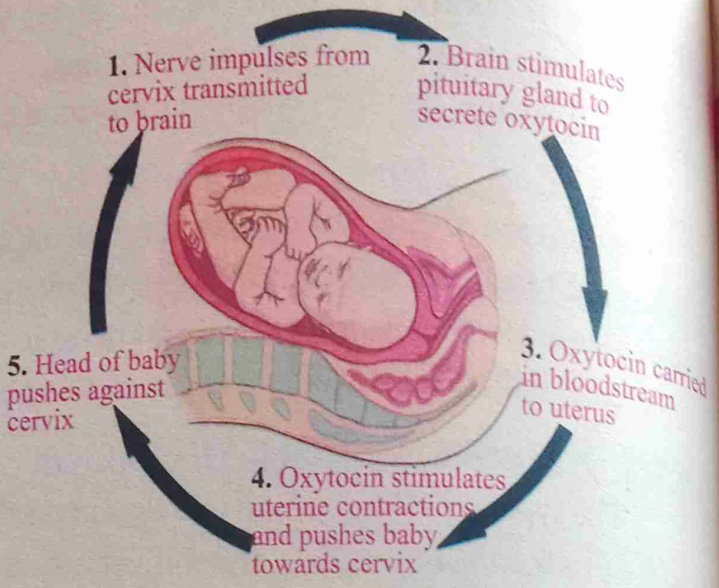


Fig. 18.10: Positive Feedback Mechanism

18.3.3 Similarities between Nervous coordination and chemical co-ordination

i) Both of these synthesize chemical messengers.
ii) Release the chemical messengers in extra cellular spaces of the body.
iii) Help in coordination of the body.
iv) Both function in response to internal or external stimuli.
v) Homeostatic in function.

Table 18.2: Differences between Nervous and Chemical Coordination

S.No.	Nervous Coordination	Chemical Coordination
i)	Electrical and chemical transmission.	Chemical transmission (hormone) through blood system.
ii)	The structural and functional units are the neurons.	The structural and functional units are hormones producing cells and neuron secretary cells.
iii)	Chemicals act where they are produced.	Hormones and neurohormones are poured into the blood which affect the target cells.
iv)	Rapid transmission and response.	Slow transmission and relatively slow acting (adrenaline an exception).
v)	Pathway is specific through nerve cells response is very localized *e.g.* one muscle.	Pathway is not specific (blood circulates whole body) target specific response may be very widespread *e.g.* growth.
vi)	Often short term changes.	Often long term changes.
vii)	The neurohormones are broken down shortly after their release.	Hormones remain active for much longer duration within the blood.

UNIT 20

REPRODUCTION

Major Concept

20.1 Reproductive system of Man
20.2 Disorders of Reproductive System
20.3 Sexually Transmitted Diseases

Learning Outcomes

Students will be able to:

- Describe the structures of male reproductive system and identifying their functions.
- Explain the principal reproductive hormones of human male and explain their role in the maintenance and functioning of reproductive system.
- Explain the structures of female reproductive system and describe their functions.
- Describe the menstrual cycle emphasizing the role of hormones.
- Describe the causes of female and male infertility.
- Explain that *in vitro* fertilization (test tube babies) is one of the methods to solve the problem of infertility.
- Define miscarriage and state its causes.
- Relate miscarriage with abortion.
- Describe the causes, symptoms and treatment of gonorrhoea and syphilis.
- Explain AIDS as a worldwide sexually transmitted disease.

Introduction

Reproduction is the biological process by which organisms give birth or give rise to new organisms which may or may not be like their parents. It helps to continue their race. This is a fundamental process and seen in all organisms. Reproduction is important for survival and maintenance of all organisms. Without this process life would come to an end. A living organism does not need reproduction to survive, but as a species, they need this mechanism for continuity and to ensure that they are not extinct.

20.1 Reproductive System of Human

The reproductive system of human is different from all other systems of body in two ways.

i) It becomes functional at the age of puberty while other systems are functional at birth or shortly after birth.

ii) The other systems are almost similar but reproductive system is quite different in male and female human.

20.1.1 Male Reproductive System

The male reproductive system performs following main functions:

i) To produce, maintain and transport semen (sperms + fluids).

ii) To discharge semen within the female reproductive tract during **sexual intercourse**.

iii) To produce and secrete male **sex hormones,** responsible for maintaining the male reproductive system.

Unlike the female reproductive system, most part of male reproductive system is located outside of the body *i.e.* **penis**, **scrotum**, and **testicles** (testes) while some parts *i.e.* vas deferens and associated glands like seminal vesicles, prostate gland and Cowper's gland are located inside the body. (Fig.20.1)

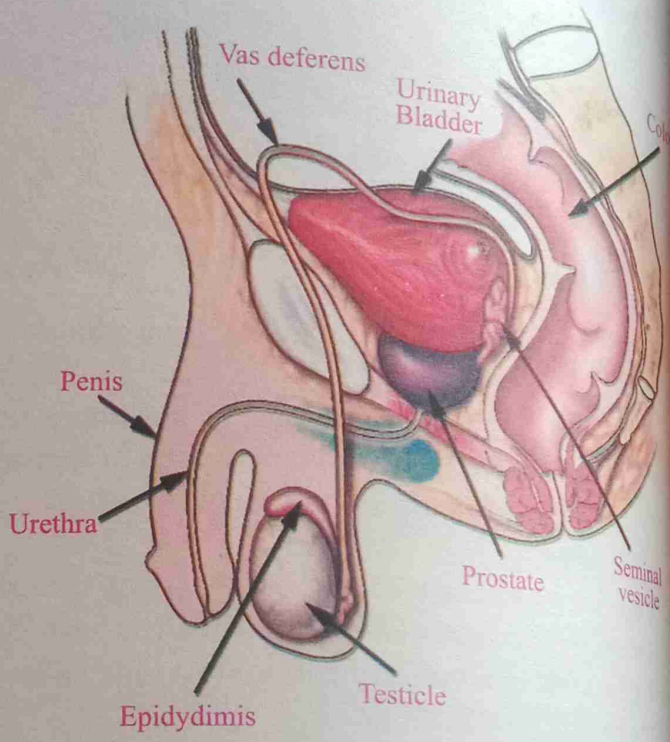


Fig. 20.1: Human Male Reproductive System

Testes

The testes (singular testis) are the male gonads. These are oval-shaped organs about the size of large olive seeds. These are located outside of body in scrotum. The scrotum is a large

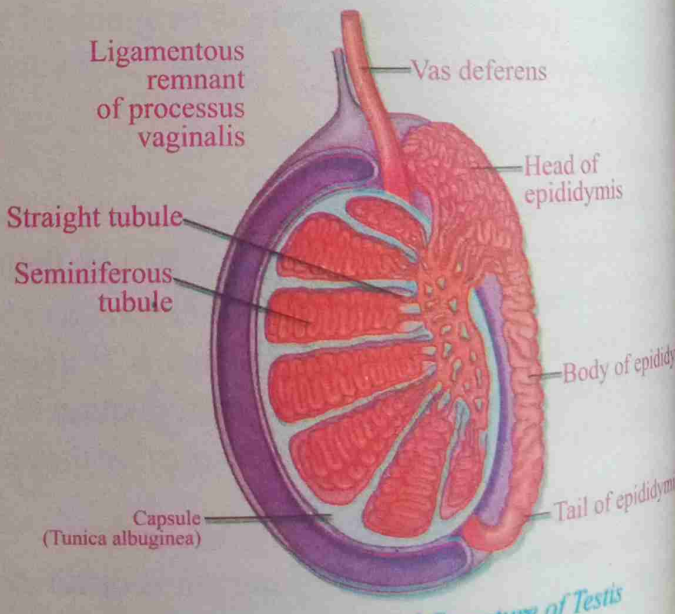


Fig. 20.2: Internal Structure of Testis

pouch like sac of skin that hangs behind and below the penis. The scrotum acts as climate control system for the testes, because for the normal sperm development, the testes must be at a temperature slightly cooler than the body temperature. The testes are usually two in number. In the testes there are coiled masses of tubules called **seminiferous tubules**. The sperms are produced in these tubules. The testes also produce male sex hormone called **testosterone** by leydig cells (interstial cells). (Fig.20.2)

Accessory Ducts

These include the following:

Epididymis:- It is a long coiled tube that rests on the back side of each testis. It stores and transports sperms. Here sperms also get mature.

Vas deferens:- It is a long muscular tube that travels from epididymis into the pelvic cavity to just behind the bladder.

Ejaculatory ducts:- The two vas deferens and two **seminal vesicles** join to form ejaculatory duct. The ejaculatory ducts empty into urethra.

Urethra:- The urethra is the tube that carries urine from bladder to outside of the body. In male, it has the additional function of ejaculating semen during sexual excitement. Therefore, urethra is also called **urinogenital duct**.

Copulatory Organ (Penis)

It is the male organ used in sexual intercourse. The skin of penis is loose and elastic to accommodate changes in penis size during an erection. The penis consists mainly of tissues that can fill with blood to cause an erection.

Accessory Glands:- Following three types of glands are associated with male reproductive system.

Extra Information

About 100 million sperms are released into the vagina during intercourse, only one of these will fertilize the egg.

Human Sperm

The human sperm has a head with a diameter of about 2.5um. It contains a large nucleus with little cytoplasm and acrosome. The nucleus carries a haploid set of chromosomes. The middle piece containing mitochondria which provide energy for sperm activity. The tail of sperm is a flagellum which enables the sperm to swim towards the egg.

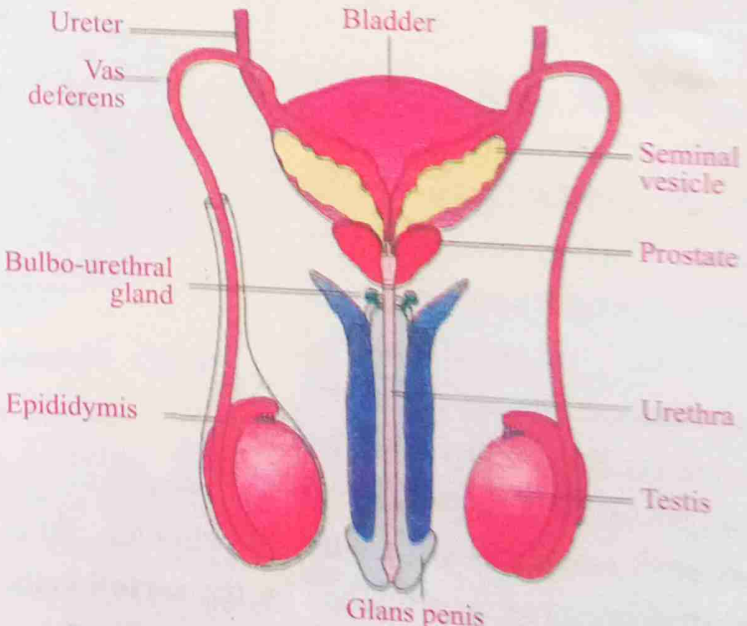


Fig. 20.3: Male Reproductive Organs (Front View)

Seminal Vesicle:- These are sac like pouches that attached to vas deferens near the base of the bladder. It produces a sugar rich fluid that provides sperms with a source of energy to help them move. (Fig.20.3)

Prostate glands

These are walnut size structure that are located below the urinary bladder at both side of urethra. The prostate gland contributes additional fluid to ejaculate, to nourish and protect the sperms.

Bulbourethral glands (Cowper's gland)

These are pea sized structures located on the side of urethra, just below the prostate glands. These glands produce a clear, slippery fluid which serves to lubricate and neutralize any acidity in urethra.

Hormonal Control of Male Reproductive Function

The entire male reproductive system is dependent on hormones. The primary hormones which involved in the functioning of the male reproductive system are: Follicle Stimulating Hormone (FSH), Luteinizing Hormone (LH) and testost-erone. (Fig.20.4)

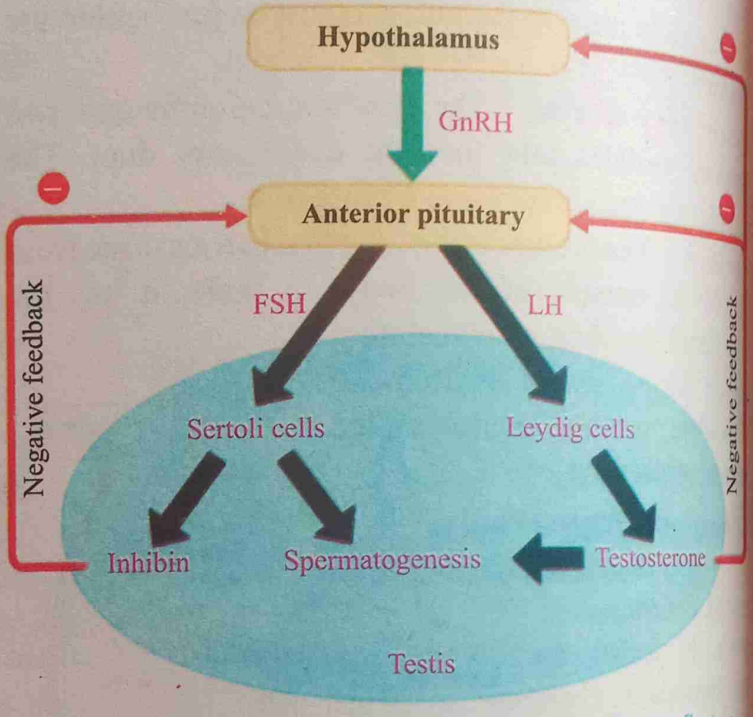


Fig.20.4: Hormonal Control of Male Reproductive System

FSH and LH are produced by the pituitary gland located at the base of the brain. FSH is necessary for sperm production and LH stimulates the production of testosterone by Leydig cells, which is necessary to continue the process of **spermatogenesis**. Testosterone also helps in the development of male characteristics, including mass and strength, fat distribution, bone mass and sex drive. **Inhibin** hormone is produced by the **sertoli cells** and controls the spermatogenesis at normal rate.

20.1.2 Female Reproductive System

The female reproductive system is more complex than the male reproductive system, because the male needs only to produce and deliver gametes. However, female reproductive system besides producing gametes also gestates, gives birth and nourishes the new born. The female reproductive system is also under the influence of menstrual cycle.

Structure of Female Reproductive System

The female reproductive system consists of following parts.

i) Ovaries ii) Ducts iii) External genitalia

i) Ovaries

There is a pair of **ovaries**, which are oval-shaped and attached to the dorsal body wall just below the kidneys. Eggs or ova develop inside the ovaries of mature female. There are approximately **4,000,00 potential (follicles) cells** are already present at birth, only about 500 will ever become mature within two ovaries and they are released from puberty to menopause. Usually, only one egg is released every month. The ovaries take turn alternate to release an egg.

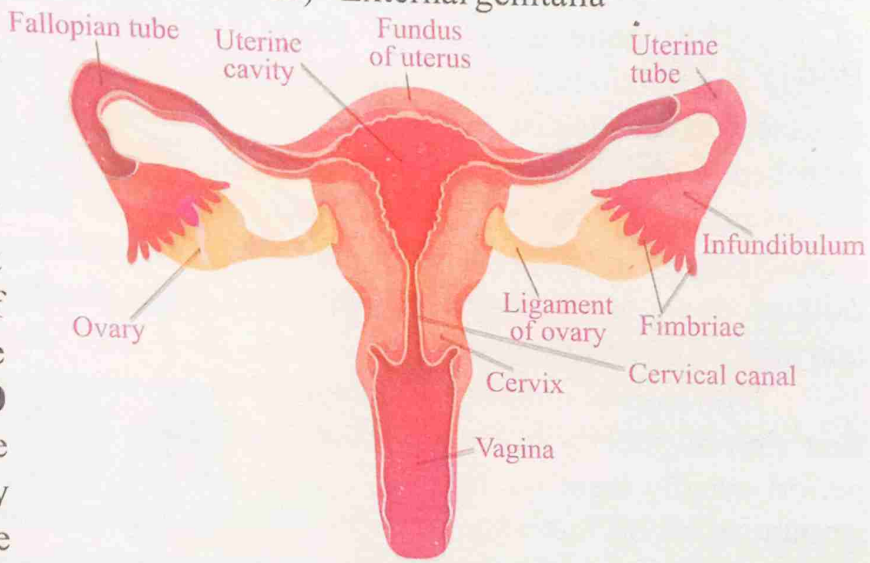


Fig. 20.5: Human Female Reproductive System

The egg is spherical in shape and about 120μm in diameter, containing a large nucleus with haploid number of chromosomes. (Fig.20.5)

ii) Oviduct (Fallopian tube or uterine tube)

The ovary releases mature egg into oviduct which is a narrow muscular tube. It leads from ovary to the uterus. The egg is fertilized in the oviduct.

Uterus

Uterus is a pear shape elastic sac about 7.5cm long. It is the site for development of **fetus**. During pregnancy, the wall of the uterus consists of three layers. The outer layer is called perimetrium, middle layer is myometrium which is thick and muscular. The inner layer is known as endometrium which is spongy lining of

Extra Information

Reproductive system contains the largest cell of the body the egg which is about **120mμ** in diameter and smallest human cell the sperm, about **5mμ** in diameter.

uterus. At the lower narrow end of the uterus is a circular ring of muscle known as cervix.

iii) External Genitalia (Vagina)

Leading from the cervix to the outside is the birth canal or vagina. It is thin walled 8-10cm long tube. The opening of the vagina is the **vulva**. Semen is deposited in the vagina during intercourse.

Extra Information

A female uterus is normally about 3 inches long and 2 inches wide which can expend up to 20 times during pregnancy. Uterus contains one of the strongest muscles in the female body.

20.1.3 Female Reproductive Cycle and its Hormonal Regulation

The female reproductive system is controlled by the follicle stimulating hormone (FSH) and luteinizing hormone (LH) which are produced by pituitary gland. Their release is controlled by hypothalamus. FSH stimulates the ovarian follicles to produce estrogen, which helps in the maturation of egg while LH stimulates the production of progesterone in ovaries. The estrogen triggers the development of secondary sexual characteristics in female. The pituitary gland also produces **prolactin**, which stimulates milk production. The **oxytocin**, which stimulates uterine contraction during child birth and milk let down during sucking.

The start of monthly discharge of blood or menses from uterus via vagina is the first sign of puberty in female. This condition is called **menstruation**. The menstrual period usually lasts for five days. However, the length of the menstrual period and amount of blood lost vary considerably with the individual. Every month, a cycle of events takes place in the female reproductive organs. This is called **menstrual cycle**. The average menstrual cycle for an adult female is 28 days. However, the menstrual cycle ranging from 21-33 days, are not abnormal. The effects of emotional disturbances, stress, mental fatigue and illness may alter or stop the menstrual cycle. An unbalance diet or malnutrition may cause the periods to be very irregular or to stop completely. A young girl may take about three years before her periods become regular.

The menstrual cycle has 4 phase:

Menstrual Phase

Menstruation is the elimination of the thickened lining of the uterus (endometrium) and blood from the body through the vagina. Menstrual fluid contains blood, cells from the lining of the uterus and mucus. The average length of this phase is 5 days.

Follicular Phase

The follicular phase starts on the stoppage of menstruation and ends with ovulation. The pituitary gland releases follicle stimulating hormone (FSH), which stimulates the ovary to produce about **5-20 follicles**. Each follicle houses an immature egg. Usually only one follicle will mature into an egg while the others die. The growth of

the follicles stimulates the lining of the uterus to thicken in preparation for possible pregnancy.

Ovulation Stage

Ovulation is the release of mature egg from the surface of the ovary. This usually occurs mid of the cycle, about 14th day of the cycle.

Extra Information

Fallopian tubes are about 12cm long and wide as a sewing needle.

During the follicular phase, the development of follicle causes a rise in the level of estrogen. The hypothalamus in the brain recognizing these rising levels and releases a chemical called **gonadotropin releasing hormone (GnRH)**. This hormone stimulates the pituitary gland to produce raised levels of luteinizing hormone (LH) and FSH within two days, ovulation is triggered by the high level of LH. The egg is funneled into the fallopian tube and toward the uterus by waves of small hair like projections. The life span of the typical egg is only around 24 hours.

Luteal Phase

During ovulation, the egg bursts out from its follicle, but the ruptured follicle stays on the surface of the ovary. For the next two weeks or so, the follicle transforms into the

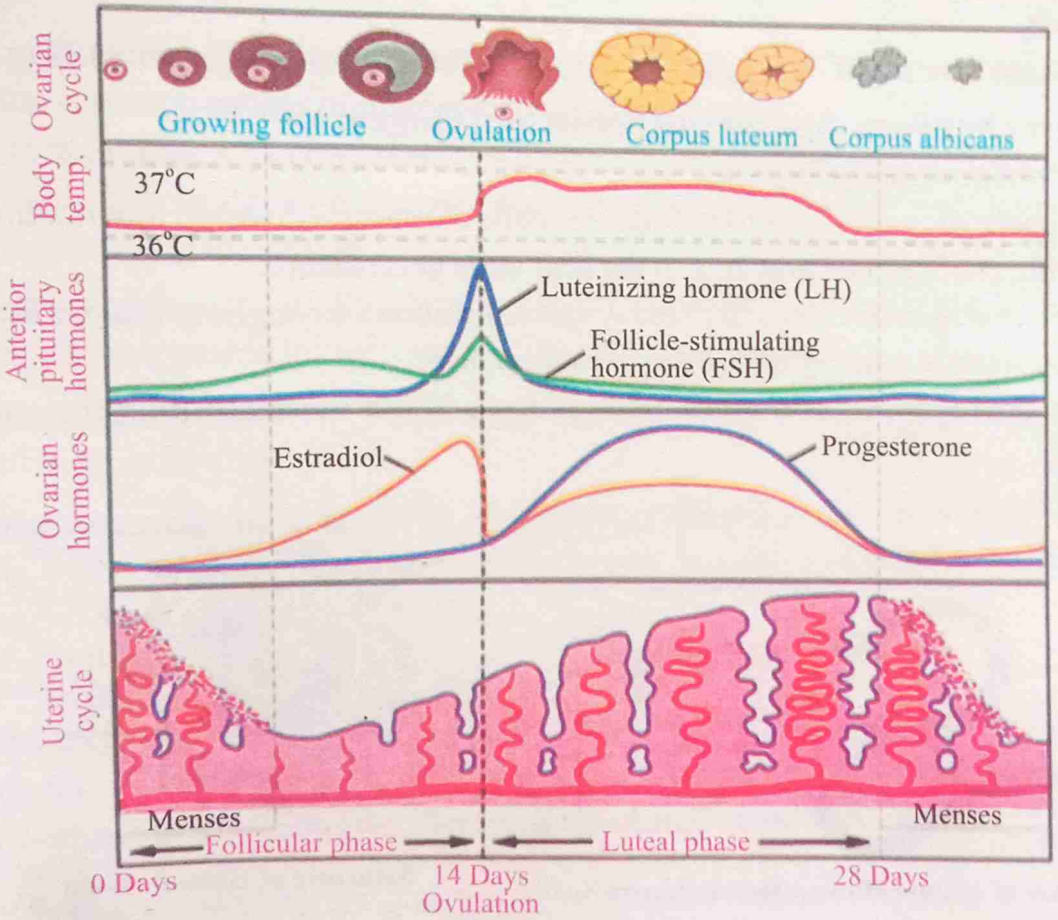


Fig.20.6: Menstrual Cycle in Human

structure called **corpus luteum**. This structure starts releasing progesterone along with small amount of estrogen. The combination of hormone maintains the thickened lining of the uterus of fertilized egg implants in the lining of the uterus. It produces the hormones that are necessary to maintain the corpus luteum. It induces the **human chorionic gonadotropin (hCG)**, the hormone that is detected in urine test for pregnancy. If pregnancy does not occur, the corpus luteum degenerates usually during day 22 after menstruation. The drop in progesterone level causes the lining of the uterus to fall away. This is known as menstruation. The cycle repeats. (Fig.20.6)

Extra Reading

Gametogenesis

- The production of gametes is known as gametogenesis.
- The process of gametogenesis occurs in gonads.
- The process of gametogenesis starts at puberty.
- There are two types of gametogenesis i.e. spermatogenesis and oogenesis.

Spermatogenesis

It is the process of sperm formation in male gonads (testes).

Oogenesis

It is the process of ova (eggs) formation in female gonads (overies). (Fig.20.7)

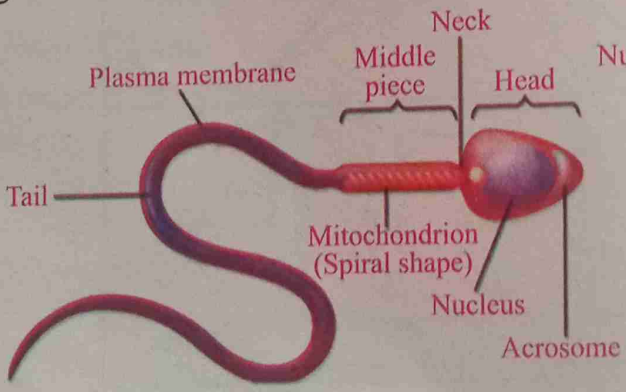
Differences between Spermatogenesis and Oogenesis

There are three differences

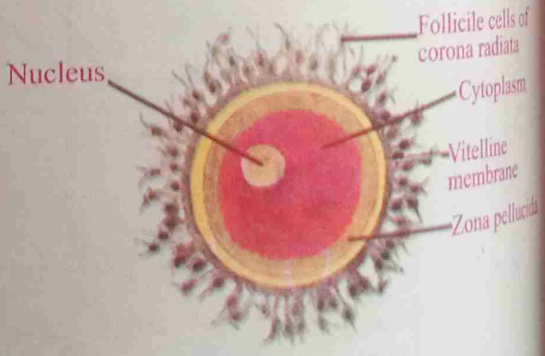
i) In spermatogenesis all four daughter cells of meiosis develop into mature gametes while in oogenesis only one of the four cells gets mature.

ii) Spermatogenesis starts at puberty and continuous throughout life while oogenesis also starts at puberty but ceases at menopause.

Spermatogenesis is a continuous process while there are long interruptions in oogenesis.



Structure of Mature Human Spermatozoan



Structure of Human Ovum

Fig. 20.7: Structure of Sperm and Egg

Terms use for Human Ovum

Zona pellucida is thick transparent membrane surrounding a mammalian ovum before implantation.

Corona radiata is many layers' thick follicle cells adhering to oocyte which supply vital proteins to the cell.

Corpus albicans is regressed form of the corpusluteum.

20.3 Sexually Transmitted Diseases (STDs)

Sexually transmitted diseases are infections that are commonly spread by sexual activity. More than 30 different types of bacteria, viruses and parasites can be transmitted through sexual activity. Some examples of sexually transmitted diseases are chlamydia, gonorrhoea, syphilis, genital herpes, AIDS, *etc*. Here only gonorrhea, syphilis and AIDS will be discussed.

Gonorrhea

It is caused by the gram positive bacterium *Neisseria gonorrhaeae*. There is no blood test to diagnose gonorrhoea. In male, typical symptoms are pain upon urination and a thick greenish yellow urethral discharge. If a baby is exposed during birth, an eye body, causing heart damage or arthritis. It is transmitted through direct contract or sexual infection leading to blindness can result. Gonorrhoea can spread to internal parts of the contact. It is treated using antibiotics penicillin or tetracycline.

Syphilis

It is caused by a spirochete bacterium *Treponema palladium*. It has three stages, which are typically separated by latent periods. In the primary stage, a hard chancre (ulcerated sore with hard edges) appears. In the secondary stage, rash appears all over the body.

During the tertiary stage, syphilis may affect the cardiovascular and nervous system. It damages reproductive organs, eyes, bones joints, central nervous system, heart and skin. Sexual contact is the major source of its dissemination. Syphilis is a very devastating disease. Control depends on prompt and adequate treatment of all cases be treated with antibiotic therapy.

AIDS-A worldwide sexually transmitted disease

AIDS is caused by a virus called HIV (Human Immunodeficiency Virus). HIV destroys the body immune system. That is why this disease is called AIDS (Human Immune Deficiency Syndrome). The HIV attacks on specific type of white blood cells called T-cells. HIV may transmit through blood transfusion, contaminated syringes, surgical instruments, *etc*. However, the most prominent cause is sexual transmission. AIDS is a major global public health issue. There are approximately 38 million people living with HIV at the end of 2019. Over two thirds of all people with HIV infection live in African region (26 million). HIV can be diagnosed through rapid diagnostic tests. However, still there is no cure for AIDS.

List the measures that can help to prevent transmission of HIV.

The HIV is transmitted from one person to another by exchanging fluids of body. Therefore, following measures should be taken to prevent transmission because prevention is so for only cure for AIDS.

- Follow the Islamic teaching and refrain from immoral sexual activities.
- Avoid sharing instruments that are likely to break the skin and be contaminated with blood *e.g.* razors and tooth brushes.
- If you require acupuncture, ear, piercing, nose piercing, *etc*. You should go to reliable operators and make sure that needles used are sterilized or insist on using disposable instruments.
- Blood of donor must be screened before transfusion.
- Use disposable syringes and sterilized operation tools for surgery.
- Affected mothers must avoid breast feeding to their infants.

22.1 Mendelian Inheritance

Mendelian inheritance refers to the patterns of inheritance that are characteristics of organisms which reproduce sexually.

Gregor John Mendel was an Austrian monk who formulated some of the fundamental principles regarding the inheritance of traits. Between 1856 – 1865, he performed number of experiments in which he cross-bred pea plants (*Pisum sativun*) with 7 pairs of contrasting characteristics Mendel explained his results by describing two laws of inheritance that introduced the idea of dominant and recessive genes. (Fig.22.1)

Character			F_2 Generation Ratio
Dominant Form	x	Recessive Form	
Purple flowers	x	White flowers	(3/4:1/4)
Yellow seeds	x	Green seeds	(3/4:1/4)
Round seeds	x	Wrinkled seeds	(3/4:1/4)
Green pods	x	Yellow pods	(3/4:1/4)
Inflated pods	x	Constricted pods	(3/4:1/4)
Axial flowers	x	Terminal flowers	(3/4:1/4)
Tall plants	x	Dwarf plants	(3/4:1/4)

Fig.22.1 Mendel's Seven Contrasting Pairs of Characters

22.1.1 Association of Inheritance with Laws of Mendel

Gregor John Mendel, through his work on pea plants, discovered the fundamental laws of inheritance. He deduced that factors (genes) come in pairs and inherited as distinct units, one from each parent. Mendel tracked the segregation of parental genes and their appearance in the offspring as dominant and recessive traits. He recognized the mathematical patterns of inheritance from one generation to the next. On the basis of his series of experiments on pea plants he formulated following laws:

> **Extra Information**
>
> On genetic level all humans are more than 99% identical.

1. The Law of Segregation

The law of segregation states that the two alleles of a single trait will separate randomly. Each inherited trait is called factor (gene) pair. Parental factors (genes) are randomly separated to the sex cells so that sex cells contain only one member of the factor (gene) pair. Offspring, therefore, inherits one allele from each parent when sex cells unite in fertilization.

2. The Law of Independent Assortment

The law of independent assortment states that the allele of one gene separate independently of another allele. Genes for different traits are sorted separately from one another so that the inheritance of one trait is not dependent on the inheritance of another.

> **Extra Information**
>
> The term Mendalian inheritance refers to a set of rules that revolve around the passing down of hereditary traits from parents to offsprings.

Inheritance of Single Trait (Monohybrid Cross)

The Law of Segregation

Mendel carefully selected 7 pairs of contrasting characters for his experiments. First he experimented plants with one pair of contrasting characters such as tallness and shortness of the plants. This type of cross which involves only one pair of contrasting characters is called monohybrid cross.

Procedure and Observations

In one of his experiments, Mendel crossed tall pea plants (about 2 meters high) with dwarf pea plants (about 20 – 50 cm). He used pure breeding varieties *i.e.* plants which when self-fertilized produced offsprings that resembled their parents. He crossed pollinated tall plants with pollen from dwarf plants and vice versa. He planted the seeds from these plants and observed the resulting hybrid which he called the **first filial generation** or **F_1 generation.** In F_1 generation all plants were tall. He then allowed F_1 plant to self-pollinate and produced seeds which gave rise to **F_2 (second filial)**

generation. In F_2 he got 1064 plants. Out of these 1064 plant 787 were tall plants and 277 dwarf plants *i.e.* in the ratio of about three tall one dwarf (3:1).

Mendel also made crosses using 6 other contrasting characters of pea plants and got almost similar results.

In all his experiments, Mendel observed that one trait or character appeared in F_1 generation while other disappeared. However, this character reappeared in F_2 generation but only in about $1/4^{th}$ of the total number of offspring. The character which appeared in F_1 generation is called **dominant** while the character which could not express itself in F_1 generation is called **recessive** trait.

Interpretation of the Results

On the basis of these experimental results Mendel was able to suggest a mechanism to explain the observations, he had made about pea plants. Infact, he suggested a model of how the inheritance of traits could be explained. Mendel concluded that:

- Hereditary characters are responsible for transmission of characteristics.
- Each characteristics is controlled by a pair of factors (genes) in the cell of an organism *e.g.* colour of flower, colour of seed, shape of seed, height of plant, *etc.*, are controlled by a pair of factor.
- If the two factors differ then only the dominant one will show its effect *e.g.* if a pea plant contains one factor for tallness and one for dwarfness, only the tall (dominant) will show the effects.
- The two factors in each pair separate or segregate during gamete formation and each gamete will contain only one factor. This statement is known as Mendel's law of segregation.

Hence when a pea plant containing a factor for tallness and a factor for shortness produces gametes. A particular gamete will either have tall factor or the dwarf factor but not both. Thus the gametes are always pure.

- The fusion of haploid gametes at fertilization restores the diploid condition in the zygote.
- Gametes unite at random so that a predictable ratio of characteristics occur among the offsprings.

Dominant Gene

It is able to express itself even in the presence of its recessive allele and does not require similar allele to produce its effect.

Recessive Gene

It is unable to express its effect in the presence of dominant allele so it produces phonotypic effect only in presence of similar allele.

Extra Information

The term dominant and recessive do not mean that an organism possessing a dominant trait is healthier or more vigorous than an organism with the recessive trait. Both dominant and recessive alleles can be disease carrier.

Inheritance of Two Traits (Dihybrid Crosses)

Mendel's Law of Independent Assortment

Mendel suggested his second law of inheritance by following two characters at the same time, such as seed color and seed shape. Pea seeds shape may be either round (smooth) or wrinkled. From single character crosses, Mendel knew that allele for yellow seed is dominant (Y), while allele of green seed is recessive (y). He also knew that allele from round seed is dominant (R), and allele for wrinkled is recessive (r).

Procedure and Observations

Mendel crossed pure **round-yellow seeded plant (RRYY)** with **wrinkled green seeded plant (rryy)** and got F_1 generation. In F_1 generation, he got all round-yellow seeded plants. However, these plants will be dihybrids *i.e.* RrYy. The key step in the experiment is to see what happens when F_1 plants self-pollinate and produce F_2 generation. If the hybrids transmit their allele in the same combinations in which the alleles were inherited from parental generation, then the F_1 hybrid will produce only two classes of gametes: RY and ry. This dependent assortment hypothesis predicts that the phenotype ratio of F_2 generation will be 3:1, just as in monohybrid cross.

Interesting Information

Pure bred means that if you let the plant self-fertilize, the offsprings will always look exactly like their parents *i.e.* if the tall plants were crossed then the offspring will always be tall.

The alternative hypothesis is that the two pairs of allele segregate independently of each other. In this example the F_1 plant will produce 4 types of gametes in equal quantities *i.e.* RY, rY, Ry, ry. If sperm of the 4 classes fertilize eggs of the 4 classes, there will be 16(4×4) equally probable ways in which the alleles can combine in F_2 generation. These combinations result in 4 phenotype categories with a ratio of 9:3:3:1. Nine will be round-yellow, three will be wrinkled yellow, three will be round-green and one will be wrinkled green. When Mendel did the experiment and obtained F_2 generation, his results were close to the predicted 9:3:3:1 phenotypic ratio. These results were supporting the hypothesis that the allele for one gene-supporting seed colour and seed shape are sorted into gametes independently of the alleles of other genes.

Interpretation of the Results

Mendel tested all seven pairs of contrasting characters in various dihybrid combinations and always observed a 9:3:3:1 phenotypic ratio in F_2 generation. Is this consistent with the 3:1 phenotypic ratio observed for the monohybrid crosses? To investigate this question, let's consider one of the two dihybrid characters by itself. Looking only in pea color we see that there are 416 yellow and 140 green peas, a 2.97:1 ratio, or roughly 3:1 ratio. In this dihybrid cross, the pea color alleles segregate as this were a monohybrid cross. The result of Mendel's dihybrid cross is the basis for what is

called **law of independent assortment**. This law states that the alleles of two (or more) different genes get sorted into gametes independently of one another. In other words, the allele a gamete received for one gene does not influence the allele received from another gene.

Limitations of the Law of Independent Assortment

This law applies only to those genes (allele pairs) located on different chromosomes (non-homologous chromosomes) or alternatively to genes that are very far apart on the same chromosome. All the pea characters Mendel chose for analysis were controlled by genes on different chromosome. This situation greatly simplified interpretation of his multi-character pea crosses.

Usefulness of Law of Independent Assortment

This law explains that desired characters of two parents can be expressed in single parents and undesired characters can be prevented from expression. Can you guess how?

Scope of Independent Assortment in Variation

The independent assortment genes also contribute in mutation because it results in the shuffling of chromosomes into various gametes. Crossing over occurs when homologous chromosomes exchange genetic information. Thus, chromosomes are formed that contain genes from both parents. (Fig.22.2)

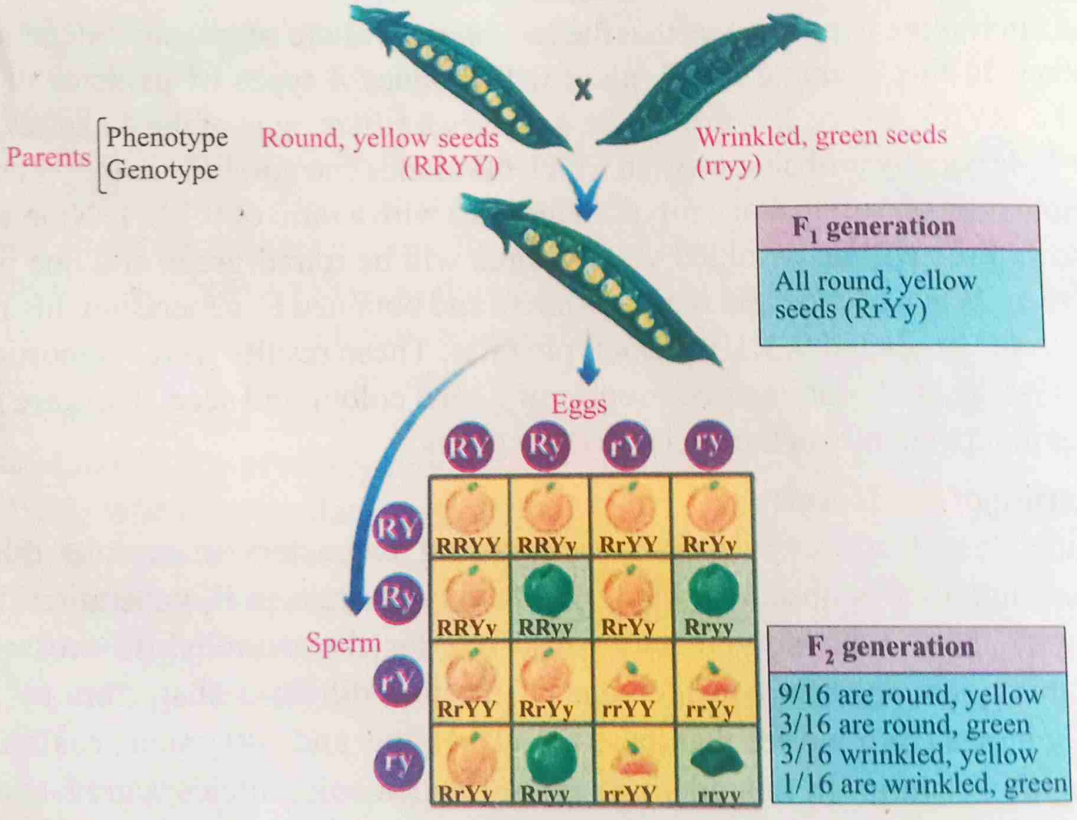


Fig.22.2 Dihybrid Cross

22.1.2 Inheritance and Mathematical Probabilities

Probability is a chance of occurring of an event. Mendel laws reflect the same rules of probability that apply to tossing coins, rolling dice and drawing cards from a deck. The probability scale range from 0 to 1. An event that is certain to occur has a probability of 1, while an event that is certain not to occur has a probability of 0 with a normal coin, the chance of tossing tails is 1/2 and chance of tossing heads is 1/2.

Tossing a coin illustrates an important lesson about probability. For every toss, the probability of head is 1/2. The out-come of any particular toss is unaffected by what has happened on previous trials.

The phenomena such as coin tosses are referred as independent events. Each toss of a coin whether done sequentially with one coin or simultaneously with many is independent of every other toss. And like two separate coin tosses, the alleles of the one gene segregate into gamete independently of another gene's alleles (the law of independent assortment). The combined probability of two or more independent events can be calculated by product rule.

Product Rule

This rule states that probability of two or more independent event occurring together can be calculated by multiplying the individual probability. This rule is useful in genetics. The product rule is used to predict frequencies of fertilization events.

According to this rule the probability of round yellow phenotype in F_2 generation of a dihybrid cross is equal to the product of individual probabilities of round (3/4) and yellow (3/4) phenotype *i.e.* $P=3/4\times3/4=9/16$.

22.2 Exceptions to Mendelian Inheritance

We know today that there are many exceptions to Mendel's laws. It means that not every gene has alleles that are strictly dominant or recessive. Does this mean that Mendel was wrong? No it means that we know more today about genetics, diseases and inheritance than 150 years ago, when Mendel formulated his laws. Some of the most common exceptions of Mendelian inheritance will be discussed here.

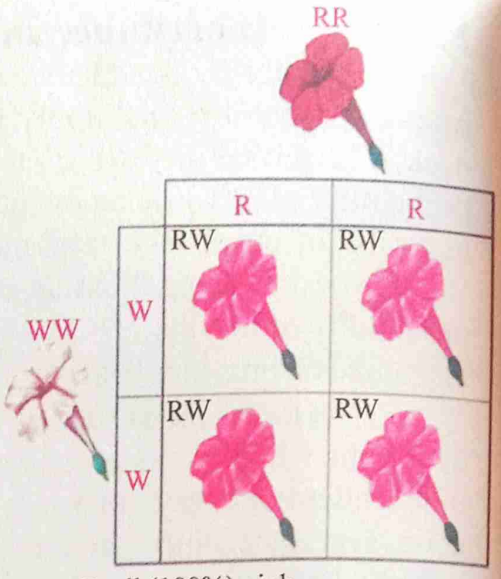
22.2.1 Incomplete Dominance

When two contrasting characters are crossed, and if in F_1 generation none of the characters is fully expressed then this phenomenon is called incomplete dominance. It was first described by Carl Correns.

Example: When red (RR) Japanese 4 o'clock flower plant (*Mirabilus Jalapa*) is crossed with white (WW) 4 o'clock flower plant, in F_1 generation hybrid plant have pink (RW) flowers. This third intermediate phenotype results from the flowers of heterozygotes having less red colour than the red homozygotes. This is unlike the case of Mendel's pea plant. (Fig.22.3)

At first glance incomplete dominance of either allele seems to provide evidence for the blending hypothesis of inheritance which would predict that red or white traits

could never reappear among offsprings from pink hybrid. In fact, inbreeding F_1 hybrids produce F_2 offsprings with a phenotypic ratio of one red to two pink to one white *i.e.* 1:2:1 ratio. Thus genotype and phenotype ratio is same (RR, 2RW, WW). The segregation of the red flower and white flower alleles in the gametes produced by the pink flowered plants confirms that the allele for flower colour are heritable factors that maintain their identity in the hybrids; that is; inheritance is particulate.



F_1 all (100%) pink

F_2 one red (25%), two pink (50%), one white (25%)

Fig. 22.3: Incomplete Dominance

22.2.2 Co-dominance

The dominance relation when two contrasting characters are crossed and in F_1 generation both of them fully express themselves is called co-dominance.

For example, the human MN blood group is determined by co-dominant alleles for two specific molecules located on the surface of red blood cells, the M and N antigen molecules. A single gene locus at which two allelic variations are possible, determines the phenotype of this blood group. Individual homozygous for the M allele MM have red blood cells with only M molecules; individual homozygous for the N allele NN have RBCs with only N molecules. But both M and N molecules are present on the red blood cells of individuals heterozygous for the M and N alleles (MN). The MN phenotype is not intermediate between the M and N phenotypes, which distinguishes co-dominance from incomplete dominance. Rather, both M and N phenotypes are by heterozygotes, since both molecules are present. (Table 22.1-22.2)

Genetic Problem

What would be expected offspring when red four O'clock plant is crossed with pink one.

Solution:

Red	X	Pink	
RR	X	RW	
RR	RW	RR	RW
Red	Pink	Red	Pink

Ratio = 2:2

Skill

What will be the result of cross between red bulls to white cow? What will be genotype and phenotype of offspring?

Table 22.1: MN Blood Group Showing Co-dominance

Genotype	Phenotype	Antigen Present on red BC
L^ML^M	M	M
L^ML^N	MN	M and N
L^NL^N	N	N

Table 22.2: Difference between Incomplete Dominance and Co-dominance

S. No.	Incomplete dominance	Co-dominance
i)	Intermediate trait appear.	Has independent effect. Both traits simultaneously appears.
ii)	Both alleles are expressed itself partially.	Both alleles are equally conspicuous.
iii)	None of the parental characteristics express in offspring.	Both parental characteristics express in offspring.

Multiple Allele

Any one of a series of three or more alternative or allelic forms of a gene, only two of which can exist in any normal diploid individual is known as multiple allele.

The ABO blood group is an example of multiple allele. It is also an example of exception to Mendelian inheritance.

The 4 blood groups A, B, AB and O are all determined by a single gene. Three alleles of this gene exist. I^A, I^B and i. I^A and I^B are dominant while i is recessive to both I^A and I^B.

22.3 Blood Group System

Although the ABO and Rh-groups are most important for blood transfusions, there are 36 other known blood group that usually do not complicate the blood transfusion are called **rare types**.

Each blood group has a combination of sugars and protein called antigens that are found on the surface of RBCs. There are about 600 antigens so there is potential for a lot of variation between different people.

22.3.1 ABO Blood Group System

ABO blood group is an example of multiple allele which is an exception to Mendelian inheritance. In 1900 **Karl Landsteiner** reported a series of test, which identified the ABO blood group system. He got noble prize in 1910 for his discovery. The ABO blood group is also found in other **primates** like apes, chimpanzees, gorillas.

Extra Information

There is no crossing over between the members of multiple allele. Crossing over takes place between two different genes only and does not occur within gene.

Antigen of ABO Blood Group

ABO antigens are glycolipid in nature, attached on the surface of red blood cells. These antigens stick out from cell membrane and there are many antigen sites per red blood cell. Besides their presence on red blood cells, soluble antigens can be present in plasma, saliva and other secretions. These antigens are also expressed on tissues other

than red blood cells. There are two types of antigens *i.e.* antigen A and B. The presence or absence of these antigens makes 4 types of blood groups *i.e.* blood group A when antigen A is present, blood group B when antigen B is present, blood group AB when both antigens A and B are present and blood group O when both antigens A and B are absent.

Genetic Basis of ABO System

Blood groups are inherited from both parents. The ABO blood group is controlled by a single gene with three types of alleles *i.e.* I^A, I^B and i. The I stands for isoagglutinogen. The I^A and I^B both are dominant alleles, while 'i' is recessive. The gene is located on long arm of chromosome no 9. The individual with genotype I^AI^A and I^Ai have type A blood group and individual with I^BI^B and I^Bi have type B blood group.

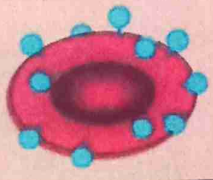
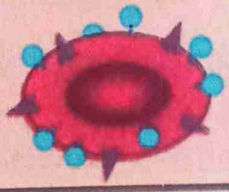
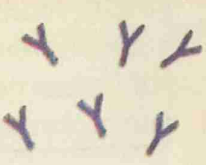
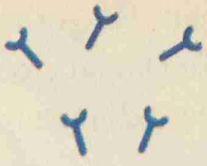
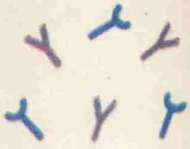
Problem

A man of blood group B and women of blood group A have three children. One is group A, one group B and one group O. What are the genotype of five people?

The genotype I^AI^B have blood group AB because both I^A and I^B alleles are dominant. An individual having genotype ii has blood group O.

Codominance: Another example of codominance is human blood type AB, in which two types of protein ("A" and "B" appear together on the surface of blood cells. (Table:22.3)

Table 22.3: ABO Blood Group Antibodies and Antigens

ABO Blood Groups				
Antigen (on RBC)	Antigen A 	Antigen B 	Antigen A + B 	Neither Antigen A nor B 
Antibody (in plasma)	Anti-B Antibody 	Anti-A Antibody 	Neither Antibody	Both Antibodies 
Blood Type	**Type A** Cannot have B or AB Blood Can have A or O Blood	**Type B** Cannot have A or AB Blood Can have B or O Blood	**Type AB** Can have any type of blood Is the universal recipient	**Type O** Can only have O blood Is the universal donor

Antibodies of ABO Blood System

Two types of antibodies are present in blood plasma. The antibodies present together with the antigens in opposite way *i.e.* **Antigen A** with anti-body B, **antigen B** with antibody A, **antigen AB** has no antibodies, none of the antigen with both antibodies A and B. There is an agglutination reaction between similar antigen and antibody. Antigen "A" agglutinates the antibody A and antigen "B" agglutinates the antibody B.

Transfusion Principle

Blood transfusion is the process of transferring blood into one's circulation intravenously. Transfusions are used for various medical conditions such as deficiency of blood, blood lost during pregnancy or any surgery, any blood cell disease like **thalassemia, sickle cell** and **leukaemia**, *etc.*

Before blood transfusion blood group of recipient and donor are tested. If transfusion is carried out between two incompatible blood groups, antigen, antibody reaction will occur in recipient and as a result agglutination *i.e.* clumping of red blood cells will occur. Therefore, the transfusions are carried out on the basis of donor's antigens and recipient's antibodies. Due to these limitations the persons with type A can receive blood from type A or O because they have anti B antibody so they cannot be given any blood carrying B antigen. The person with blood type B can receive blood from a person with blood group B or O. The person with blood group AB can receive blood from all other types *i.e.* A, B, AB and O while a person with blood group O can only receive blood from its own type. Therefore, blood group 'O' is called universal donor and blood group AB is called universal recipient.

Extra Information

An erythroblast is a type of RBC which still retains a cell nucleus. It is intermediate precursor of normal erythrocytes.

Genetic Problem

The woman with blood group B has a child with blood group O what is the genotype of mother and child? What are the genotypes father could have?

Genetic Problem

The father has hybrid blood type 'A' and mother hybrid blood type B what are possible blood groups of their children?

Guess

The blood group O is more frequent in human population. Can you expl-ain why this is so?

Interesting Information

ABO blood group antigens are not only found on the surface of RBCs. They are also normally secreted by some people in their body fluids, including saliva, tears and urine. Such persons are called antigen secretors. Whether someone is able to secrete them is generally controlled by dominant secretor gene "Se" present on chromosome 19.

22.4 Rh Blood Group System and Erythroblastosis Foetalis

Rh blood group system is defined on the basis of Rh factor present on the surface of red blood cells. Rh factor is another blood group system. The ABO blood type is represented by + or – sign. The +ve sign indicates the presence of Rh factor while –ve sign indicates the absence of Rh factor. Landsteiner discovered Rh antigen from the blood of Rhesus monkey in 1930.

Antigens of Rh Blood Group System and Genetic Basis

Rh blood group system is encoded by three genes C, D and E. These genes occupy two loci *i.e.* locus D and C or E loci. Gene D is located on D locus while the gene C or E located on other locus. However, D locus has prime importance. The gene D has two alleles, D and d. D is completely dominant over d. Therefore, the person with DD or Dd are Rh +ve. The person dd genotype is Rh –ve.

The O –ve blood type is **universal donor** because it can donate blood to all blood groups. The AB +ve is **universal recipient** because it can receive blood from all blood groups.

Table 22.4: ABO and Rh Blood Groups system

Recipient	Donor							
	O-	O+	A-	A+	B-	B+	AB-	AB+
O-	✓	✗	✗	✗	✗	✗	✗	✗
O+	✓	✓	✗	✗	✗	✗	✗	✗
A-	✓	✗	✓	✗	✗	✗	✗	✗
A+	✓	✓	✓	✓	✗	✗	✗	✗
B-	✓	✗	✗	✗	✓	✗	✗	✗
B+	✓	✓	✗	✗	✓	✓	✗	✗
AB-	✓	✗	✓	✗	✓	✗	✓	✗
AB+	✓	✓	✓	✓	✓	✓	✓	✓

Extra Information

The positive blood groups can receive all times nega-tive blood groups while negative blood groups can only receive one time positive blood group but not second time.

Anti Rh-antibody and Transfusion Principle

The Rh antibody is not present naturally in the body. This antibody is produced in reaction of Rh antigen. Rh +ve donor is totally incompatible for Rh –ve recipient. Sometimes Rh –ve person receives Rh +ve antigen through wrong Rh +ve blood transfusion. He starts producing anti Rh antibodies against Rh antigen and reaction occurs.

A donor who has never been exposed to Rh antigen can be transfused to Rh +ve recipient.

22.4.1 Erythroblastosis Foetalis

Erythroblastosis foetalis or **hemolytic disease** (Haemo : blood, lytic : breakdown) of new born babies occurs when baby's red blood cells break down at a fast rate. Erythroblastosis foetalis develops in a foetus, when anti-Rh antibodies produced by the mother pass through the placenta and start **hemolysis**.

Problems and Complications in Foetus

Babies who suffer erythroblastosis foetalis, develop the symptoms of anaemia, pale and swollen body at birth. Enlarged liver or spleen. The anaemic foetus starts to release many immature erythroblastosis into his blood system; therefore, the disease is called erythroblastosis foetalis. The anaemic foetus may lead to abortion or still birth. If the pregnancy continues the liver and spleen produce and breakdown RBCs at fast rate. The breakdown of RBCs produces **bilirubin**. The high concentration of bilirubin in foetus blood damages brain and turns the skin yellow. This condition is called **jaundice**.

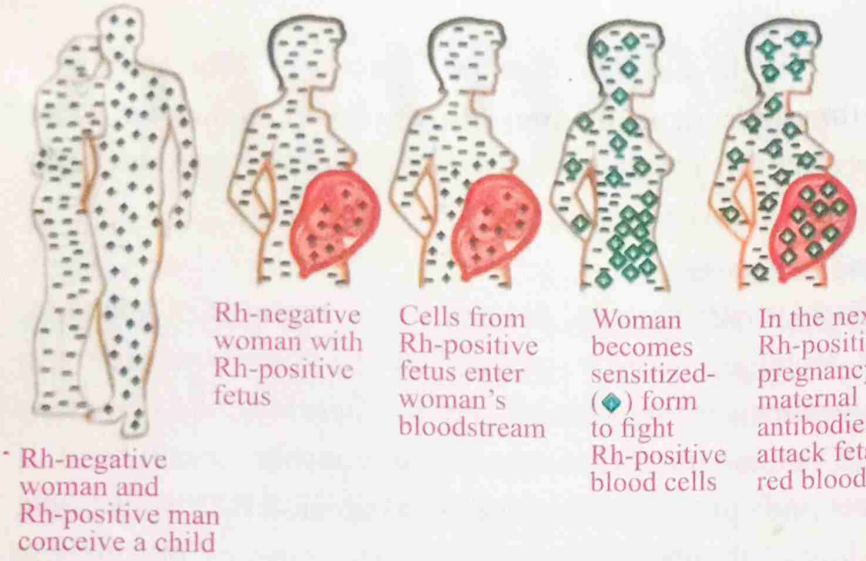
Causes and Risk Factors

The most common cause of erythroblastosis foetalis is **maternal foetal** Rh **incompatibility**. Sometime, an Rh –ve woman marries to an Rh +ve man. The women conceive a child with Rh +ve blood group maternal foetal Rh incompatibility. If the man's genotype is DD, all offspring will have Dd genotype *i.e.* Rh +ve. If the man genotype is Dd, half of the offsprings will be Dd *i.e.* Rh +ve while half of the offsprings will have genotype dd *i.e.* Rh –ve.

The Rh –ve offspring will remain safe in mother body but Rh +ve offsprings will be at risk in mother's body. Can you guess how?

Prevention and Treatments

During a pregnant woman's first prenatal doctor's visit, she should be screened for blood and Rh type. If she has Rh-negative blood, the father's blood and Rh type should be tested. If the father has Rh-positive blood, then Rh-positive foetus may develop in the woman. In this cause the Rh sensitization of Rh-negative mother can be avoided by a simple therapy. In this therapy she is given an injection of Rh antiserum (serum containing anti-Rh antibodies) during early pregnancy (1st trimester) and immediately after birth within 72 hours of delivery. This causes any of the baby's red blood cells that may have crossed into the mother's blood to be destroyed before sensitizing the mother's immune system to produce maternal anti-Rh antibodies. The injected antiserum disappears before the next pregnancy. This has to be done with each pregnancy whether it ends in a delivery or an abortion. (Fig.22.4)



Genetic Problem

An Rh negative woman marries to an Rh positive man. The father of man was also Rh –ve. What will be the possible genotypes of their offsprings? What will be the chances of erythroblastosis foetalis?

Fig.22.4: Maternal Foetal Rh-incompatibility

22.5 Polygenic Inheritance and Epistasis

Polygenic inheritance, also known as **quantitative inheritance**, refers to a single inherited phenotypic trait that is controlled by two or more different genes.

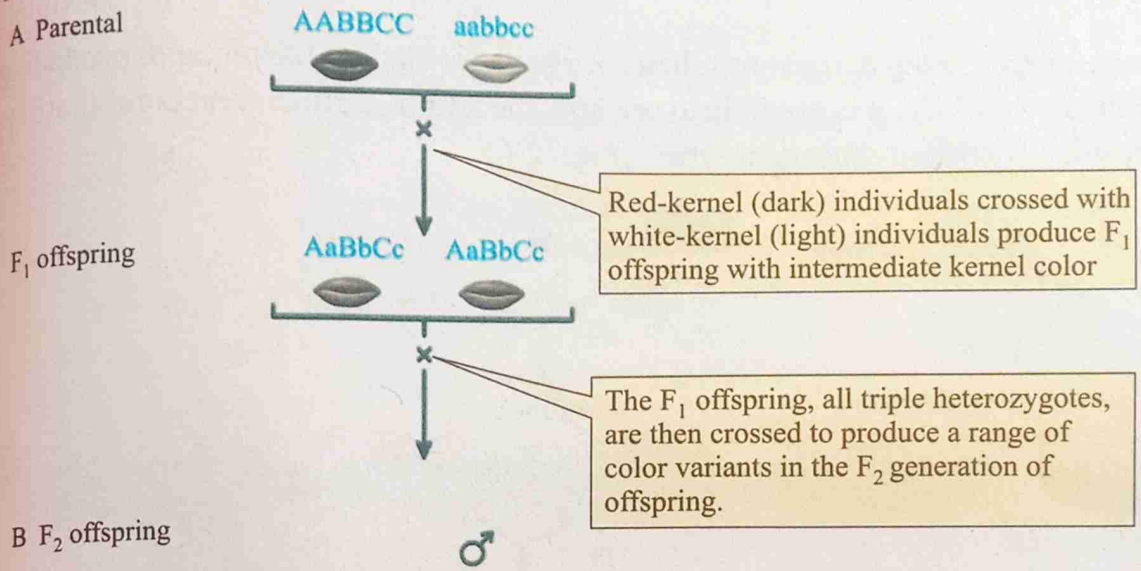
The traits that are determined by polygenic inheritance are not simply an effect of dominance or recessive trait and do not exhibit complete dominance. Infact polygenic inheritance exhibits incomplete dominance so the phenotype displayed in the offsprings, is a mixture of phenotypes displayed by the parents. Each of the genes that contributes to a polygenic trait has an equal influence and each of the alleles has an additive effect on the phenotype outcome.

The polygenic inheritance should not be confused with the effects caused by multiple alleles.

22.5.1 Wheat Grain Colour (an example of polygenic inheritance)

Nilsson Ehle performed many crosses between varieties of wheat having red seeds and those having white seeds. The noteworthy feature of his experiment was the variation in the intensity of the red pigment in the wheat grains produced by F_2 plants. There were many gradations from the deep red of one parent to pure white of the other parent so that plant could be divided into 7 different colour classes in the ratio of 1, 6, 15, 20, 15, 6, 1. Nilsson Ehle could distinguish 6 phenotypic classes with varying intensities of red as follows: 1 deep red, 6 dark red, 15 reds, 20 mediums red, 15 light red and 6 very light red. Only one of 64 plants produced completely white grain and other one of 64 had red grains identical to the parents in the first cross. (Fig.22.5)

Nilsson Ehle postulated three pairs of genes controlling grain colour in wheat with genes for red (ABC) dominant over genes for white abc. It is also appeared that all alleles contributed equally in the production or absence of red pigment. Each of the three gene pairs when considered singly in crosses segregated in expected Mendelian fashion producing F_2 progeny of three red and 1 white.



All contributing	= 1/64
5 contributing	= 6/64
4 contributing	= 15/64
3 contributing	= 20/64
2 contributing	= 15/64
1 contributing	= 6/64
All non-contributing	=1/64

Fig.22.5: Inheritance of Wheat Grain Colour

22.5.2 Inheritance of Human Skin Colour

The pigment melanin is responsible for dark coloration in the skin and there are at least three genes, which control human skin colour. Using a hypothetical example where the production of melanin is controlled by contributing alleles denoted as A, B and C resulting in dark skin colour, and therefore, light skin color is

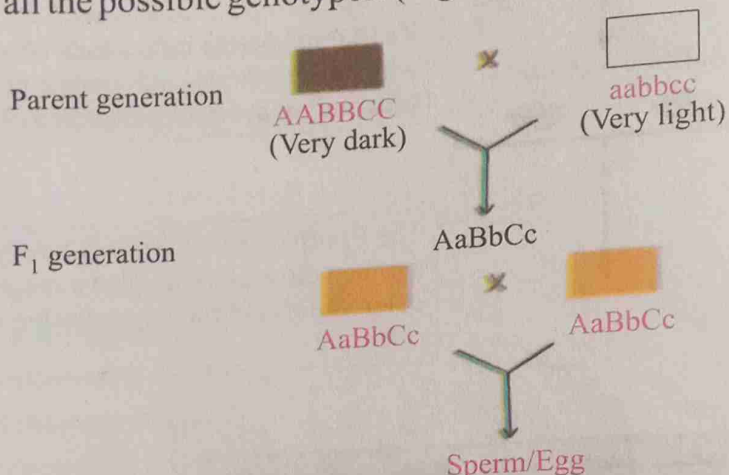
What is Pleiotropy?

The ability of a single gene to have multiple phenotypic effects *e.g.* sickle cell anaemia causes multiple systems, only one of which is the actual sickle celled conditions.

produced by non-contributing allele, denoted as a, b and c, it is possible to see how the spectrum of different skin color can result in the offsprings.

It is important to remember that in polygenic inheritance alleles do not display dominance over other rather each contributing allele gives an additive effect rather than masking effect, and so the way that the alleles interact is different to those in Mendalian genetics.

In an example using two parents, heterozygous for each of the melanin producing genes AaBbCc × AaBbCc, it is possible to see how the additive effects and combinations of alleles result in all the possible genotypes. (Fig.22.6)



Male

Gametes	ABC	ABc	AbC	aBC	Abc	aBc	abC	abc
ABC	6	5	5	4	5	4	4	3
ABc	5	4	4	3	4	3	3	2
AbC	5	4	4	3	4	3	3	2
aBC	4	3	3	2	3	2	2	1
Abc	5	4	4	3	4	3	3	2
aBc	4	3	3	2	3	2	2	1
abC	4	3	3	2	3	2	2	1
abc	3	2	2	1	2	1	1	0

Female

F_2 generation

Very light fair | Very fair | Fair | Light brown | Medium brown | Brown | Very Dark

Fig.22.6: Inheritance of Human Skin Colour

22.5.3 Epistasis

"Epistasis" is a word composed of Greek roots that means "standing upon". The epistasis is a form of interaction between non allelic genes in which one combination of such genes has a dominant effect over other combinations. A gene is said to be **epistatic** when its presence suppresses the expression of a gene which is present on another locus of same or other chromosome.

The gene which is suppressed is known as **hypostatic gene**.

Epistasis is different from dominance because dominance is the phenomenon in which the alleles of the same locus interact with each other to produce a phenotype. While epistasis is a type of interaction that occurs between alleles of different loci. (Table 22.5)

Bombay Phenotype

The Bombay Phenotype discovered in 1952 in Bombay city of India. Individuals with the Bombay phenotype have the genes to make the ABO antigen at one loci but lack the genes that produce the H substance produced at another locus. Individual with Bombay phenotype can receive blood from other individual with blood group O but cannot donate blood.

Table 22.5 Difference between Dominance and Recessive Epistasis

S.No.	Epistasis	Dominance
i)	This type of gene interaction involves two non-allelic pairs of genes.	In this type only one pair of gene is involved, therefore, there is no interaction.
ii)	One pair of gene masks the effect of another pair of genes.	An allele mask the effect of another allele of the same gene pair.
iii)	Expression of both the dominant and recessive alleles may be suppressed by the epistatic gene.	Expression of recessive allele is masked by dominant allele.

Relationship of Epistasis with Polygenic Inheritance

The epistasis is a type of polygenic inheritance where the alleles at one gene locus can hide or prevent the expression of alleles at a second gene locus. **Labrador retrievers** (type of dog) one gene locus affects coat colour by controlling how densely the pigment eumelanin is deposited in the fur. A dominant allele (B) produces the black coat while the recessive allele (b) produces a brown coat color. However, a second gene locus control whether any eumelanin at all is deposited in fur. Dogs that are homozygous recessive at

Continuous and Discontinuos Variation

Continuous variation is where there is complete range of measurements from extreme to another *e.g.* height, weight, skin color. Discontinuous variations are where individuals fall into distinct categories *e.g.* pea plants with either purple flower or white flower, tongue roller and non-roller in human.

this locus (ee) will have yellow fur no matter which alleles are at the first locus.

The polygenic inheritance is not controlled by a single gene locus, but by the combined interaction of many gene loci. In epistasis, the interaction between genes is antagonistic, such that one gene masks or interferes with the expression of another. An example of epistasis is pigmentation in mice. The white type coat color, agouti (AA), is dominant to solid colored fur (aa). However, a separate gene (c) is necessary for pigment production. A mouse with a recessive (c) allele at this locus is unable to produce pigment and is albino regardless of the allele present at locus "A". Therefore, the genotype AAcc, Aacc and aacc all produce the same albino phenotype. A cross between heterozygotes for both genes AaCc × AaCc would generate offspring with a phenotypic ratio of an agouti 3 solid color: 4 albinos. In this case, the gene 'c' is epistatic to the 'A' gene.

Coat Color in Labrador Retriever

The Labrador retriever is highly popular type of dog found all over the world. This dog is trained to perform different task *e.g.* screening and detection work for law enforcement agencies. These are also used for hunting. There are three basic coat color in the Labrador: black, yellow and chocolate. (Fig.22.7)

Fig. 22.7: Three types of Labrador Retriever

In Labradors, the B and E genes result in black, yellow and chocolate Labrador *e.g.* BB become a black Labrador. The Bb dog is also black but it carries the chocolate gene which can be passed on its offspring. So bb genotype have chocolate Brown coat color while yellow Labrador is characterized by a recessive epistatic gene (ee). But every Labrador retriever has both sets of genes which can come in any combination of capital and lower case letters *i.e.* dominant and recessive alleles. Regardless of the combination of B genes, any time the ee genotype is present, it masks the B coloration *e.g.* BbEE dog would have a black coat but Bbee dog would have a yellow coat. The black Labradors are dominant, therefore, having the most possibilities. Both yellow and chocolate Labradors are recessive, but because a yellow Labradors 'ee' genes mask both the black and chocolate coloration. So yellow Labradors are more common than chocolate Labrador. (Fig.22.8)

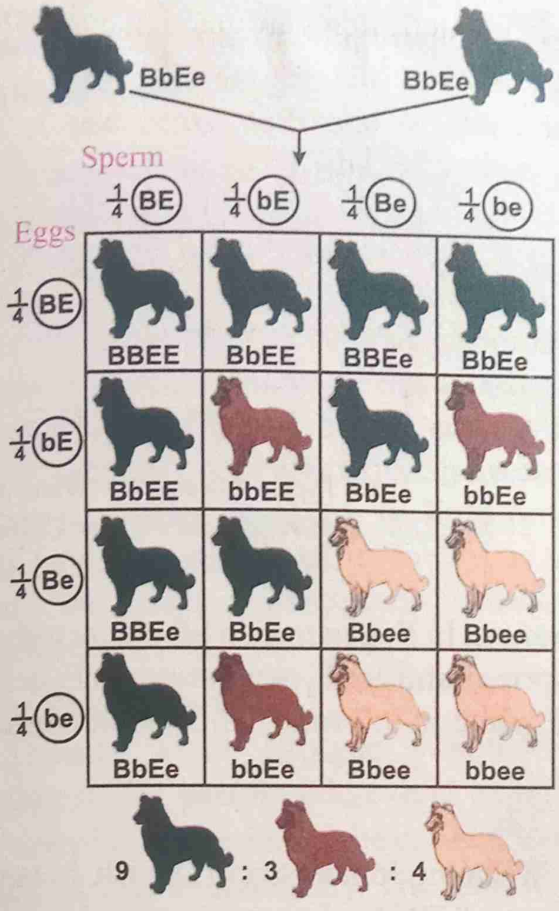


Fig.22.8: Inheritance of Coat Color of Labrador Retriever

Genetic Problem

Based on the combination of alleles can you determine what coat color a Labrador puppy could have if its father was BbEE and its mother bbEe?

Genetic Problem

When two chocolate colored Labradors were crossed, a yellow puppy was born, what is the possibility of yellow coat colored puppy if the parents are again crossed?

Inheritance of Flower Color (Pigment phenotype) of Sweet Pea *(Lathyrus odoratus)*

Batson and Punnett studied the genetic control of flower color in the sweet pea. It is an example of duplicate recessive epistasis. The flowers in this plant are either purple or white. The flowers will be purple if they contain anthocyanin pigment and flowers will be white if they do not contain this pigment. The production of anthocyanin is controlled by two different gene loci. The presence of at least single dominant allele of both the gene pairs is required for the production of anthocyanin. The dominant allele of one gene 'A' acts on a colorless precursor (substrate A) to produce an intermediate colorless product, which on getting activated by dominant allele of the second gene 'B' result is the formation of anthocyanin pigment leading to production of purple colored flower. Thus dominant alleles 'A' and 'B' complement each other to produce purple color. This type of interaction is also called

Mutation

Mutation is a change in either the amount or arrangement of genetic material (DNA). If a mutation occurs in gamete, the resulting genetic change can be inherited. There are also mutations which occur in normal body cells. These are called somatic mutations. They are responsible for different type of cancer and not transmitted in offsprings.

complementary gene interaction because it involves the interaction of both the genes. If anyone locus has homozygous recessive genotype *i.e.* AAbb or aaBB then it will interfere with dominant allele and hide their expression of purple color and flowers will be white in color. In this case the epistatic alleles are recessive and both types of recessive alleles cause same epistatic effect so this type of epistasis is called duplicate recessive epistasis.

Parents: Purple flower AABB × White flower aabb

F_1: AaBa Purple flower

	AB	Ab	aB	ab
AB	AABB [P]	AABb [P]	AaBb [P]	AaBb [P]
Ab	AABb [P]	Aabb [W]	AaBb [P]	Aabb [W]
aB	AaBb [P]	AaBb [P]	aaBB [W]	aaBb [W]
ab	AaBb [P]	Aabb [W]	aaBb [W]	aabb [W]

P = Purple flower, W = White flower

Fig.22.9: Inheritance of Flower Color in Sweet Pea

Batson and Punnett crossed white flower plant AAbb with another white flowered plant aaBB and got F_1 generation. In F_1 generation all plants were purple flower plants. Then they self-crossed F_1 offsprings and got F_2 generation. In F_2 generation they got two types of plants *i.e.* purple and white in 9:7 ratio. This result confirms the duplicate recessive epistasis. (Fig.22.9)

22.6 Gene Linkage and Crossing Over

The term gene was introduced by Wilhelm Johannsson (Danish botanist and geneticist) in 1909. Gene is a small segment of DNA as chromosome. It consists of specific sequence of nucleotides which code a specific protein or polypeptide chain. The place on chromosome where the gene resides is called the **gene locus**. Mendel did not know about gene. He used the term **factor or element** which is now called gene.

22.6.1 Gene Linkage

Genes that are located on the same chromosome are called linked genes. Alleles for these genes tend to segregate together during meiosis, unless they are separated by crossing over. Crossing over occurs when two homologous chromosomes exchange segments during meiosis. The close together two genes are on a chromosome, the less likely their alleles will be separated by crossing-over.

Linkage explains why certain characteristics are frequently inherited together *e.g.* genes for hair color and eye color are linked, so certain hair and eye colors tend to be inherited together such as brown hair with blue eye.

If genes are linked at autosomes, called **autosomal linkage** and if genes are linked on sex chromosomes, called **sex linkage**. Linked genes violate the law of independent assortment because these genes are not free to participate in independent assortment.

Detection of Gene Linkage

A test cross is an ideal method to know whether the genes are linked or not. Any

deviation from the ratio of offsprings as expected by the law of independent assortment is to be verified for linkage. A test cross with one of the parents being homozygous recessive. All the offsprings exhibit the possible combination of traits in equal ratio if the alleles are not linked and other parents of the original cross is heterozygous. Any significant deviation from this indicates the possibility of linkage. Approaches to test cross can include two-point test crosses for double heterozygous and three point test crosses for analysis with three genes. If offsprings in test cross are all parental types than it is called **complete or light linkage** and if less recombinant and more parental types are produced, then this is called **incomplete or partial linkage.** To determine the effect of linkage on inheritance, Morgan performed an experiment on Drosophila (fruit fly).

SRY Gene Located on Y chromosome encodes a transcription factor protein which controls expression of other genes. It stimulates male development *i.e.* developing testes, secrete anti mullerian hormone and destroy female structure. Testosterone hormone develop the male structure.

Morgan Experiment

Thomas Hunt Morgan (1866-1945) was an American geneticist and embryologist. He performed several experiments on ***Drosophila melanogaster*** (fruit fly). In one of his experiments he crossed long winged and broad abdomen with vestigial wing and narrow abdomen fly. The long wing and broad abdomen are dominant while

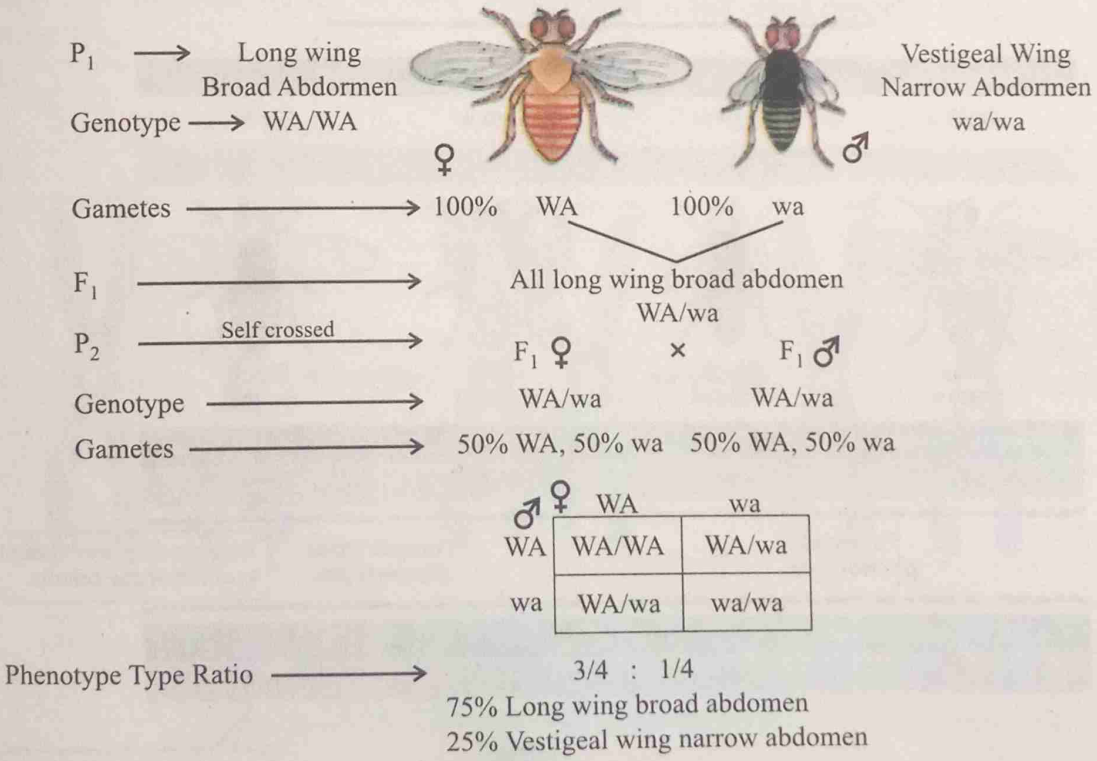


Fig.22.10: Morgan Experiment

vestigial wing and narrow abdomen are recessive traits. So in F_1 generation all flies were long winged and broad abdomen. Then he self-crossed two flies of F_1 generation. In F_2 generation he obtained 3/4 of offspring with long wings and broad abdomen and remaining 1/4 of the total had vestigial wings and narrow abdomen. (Fig.22.10)

Interpretation of Results

These results were unexpected and violation of Mendel's law of independent assortment *i.e.* 9:3:3:1. Morgan concluded that the genes of long wings and broad abdomen located on the same chromosome, so they could not assort independently during meiosis and rather inherited together. Therefore, no recombinant types were produced.

Linkage Detection

Gene linkage can only be detected accurately if the number of offsprings are quite large. It is because the probability *i.e.* chance of occurring an event determine the kind of gametes and chances of their fusion. Thus as large number of offsprings will be, the more chance of accuracy in detection of result. More parental type and less or no recombinant

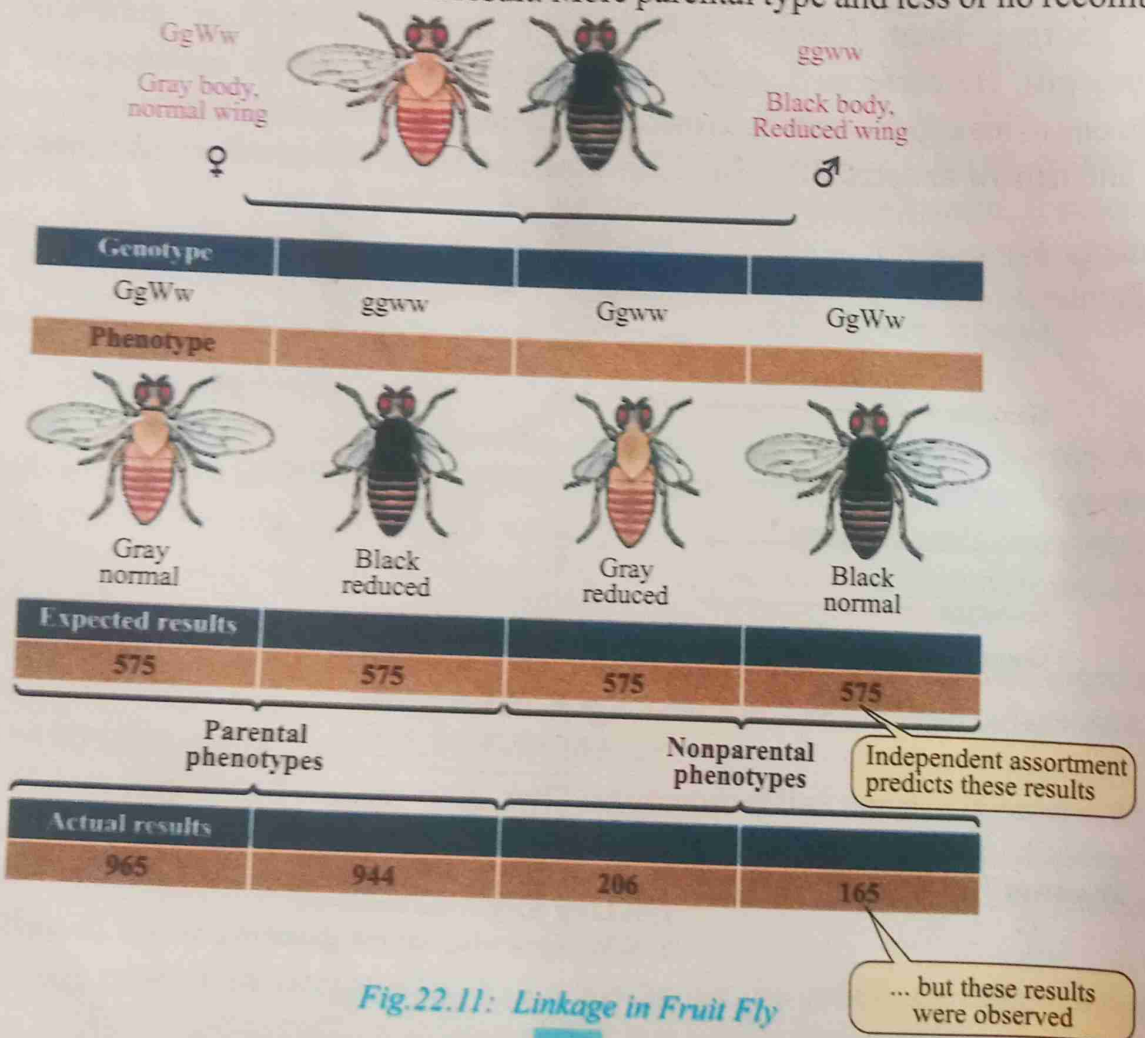


Fig.22.11: Linkage in Fruit Fly

is indication of gene linkage. For detection of linkage Morgan mated the dihybrid (Gg Ww) with recessive parental type flies (gg ww). Morgan's result was very different from the results, he expected based on the law of independent assortment *i.e.* 1: 1: 1: 1, while the actual result were quite different *i.e.* more parental types and less recombinant types. (Fig.22.11)

Crossing Over

During the formation of gametes, the homologous pairs of chromosomes exchange their segments. This process is called crossing over. Crossing over results in a shifting of genetic material and an important cause of genetic variation. The crossing over brings alleles together in new combinations. When these alleles distribute in gametes, a wide variety of gametes are produced. This is why the siblings are not identical. The cross-over data may also be used to determine the location of gene on chromosome *i.e.* gene mapping. (Table 22.6) (Fig.22.12)

Table 22.6: Difference between Crossing Over and Linkage

S. No.	Crossing Over	Linkage
i)	It leads to separation of linked gene.	It keeps the genes together.
ii)	It involves non-sister chromatids of homologous chromosomes.	It involves individual chromosome.
iii)	It increases variability.	It reduces variability.
iv)	It provides equal frequency of parental and recombinant type in test cross progeny.	It provides higher frequency of parental type in test cross progeny.

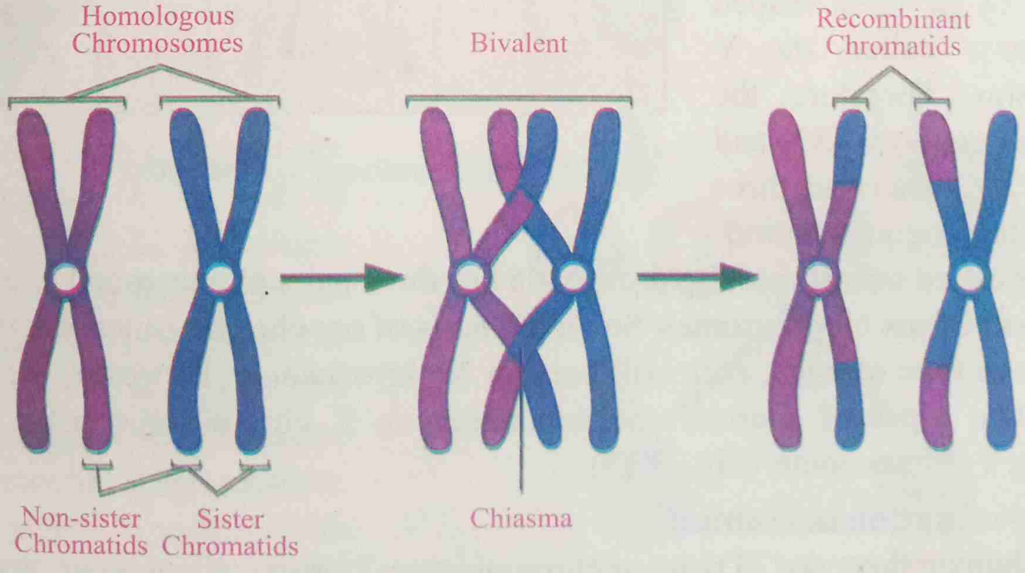


Fig.22.12: Chromosomal Crossing Over

22.8 Sex Linkage

The sex chromosomes (X and Y) contain genes which are related to sexual character (traits) of male and female. However, besides controlling sexual traits, the sex chromosomes also contain other genes which are not concerned with sexual traits. This phenomenon is called sex linkage *e.g.* gene for **blood clotting factor VIII**, gene for **opsin pigment** in eye, gene for **hairy pinna**, *etc.* An allele that is located only on X-chromosome (*i.e.* non-homologous portion) is called **x-linked**. The allele that is only located on the (non-homologous portion) of Y chromosome is called **Y-linked or holandric traits**. All those such allele which are located on homologous portion of X and Y chromosome are called **XY linked genes or pseudo-autosomal genes** because their pattern of inheritance is like autosomal genes.

22.8.1 Sex Linkage in Drosophila

T.H Morgan (1910) for the first time discovered sex linkage in Drosophila. Morgan when experimenting noted the sudden appearance of one white eyed male in the culture of normal red eyed Drosophila. This white eyed male was crossed with red eyed female. The F_1 flies were all red eyed indicating that white eye color is recessive to normal red eye color. When these F_1 flies were self-crossed freely, the red and white eyed flies appeared in the ratio 3:1 in F_2 generation. The white eyed flies were male. Among the red eyed flies two third were female and one third

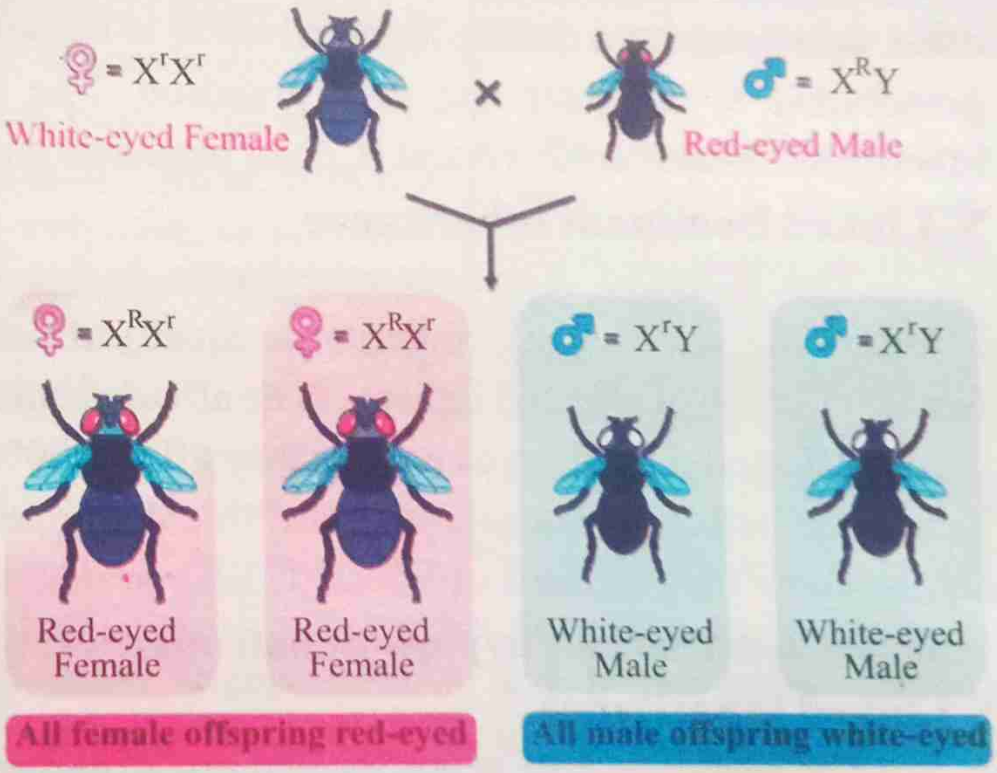


Fig.22.18: Sex determination in Drosophila

were male. The female are all red eyed whereas 50% males were white eyed and remaining 50% male were red eyed. When a reciprocal cross was performed between white eyed female and red eyed male, all female in F_1 generation are red eyed and all male are white eyed. When these two types of individuals from F_1 generation were self-crossed, female population in F_2 generation will consist of 50% red eyed and 50% white eyed individuals.

Similarly, the male population in this generation consists of 50% red eyed and 50% white eyed individual. (Fig.22.18)

Morgan Conclusion

On the basis of these results Morgan concluded that the white eye trait gene is located on X chromosome and this gene is recessive for eye color.

22.8.2 Sex Linkage in Humans

There are many traits in human which are linked with sex chromosomes. The sex linked traits may be X-linked or Y-linked. The X-linked may be recessive or dominant.

X-Linked Recessive Inheritance

The X-linked recessive inheritance is due to recessive allele on X chromosome. These are more common in male than female. It is because female possessing one X-linked recessive is considered carrier. A female for X-linked recessive trait can only be affected if it carries allele on its both X chromosomes. On the other hand, as male has only one X chromosome, so if a recessive allele is present on X chromosome it will express itself. A father cannot donate X-linked allele to his son. So pattern of inheritance is from grandfather to daughter and then grandson. The examples of X-slinked recessive inheritance is haemophilia A and B, color blindness and testicular feminization.

X-Linked Dominant Inheritance

The X-linked dominant inheritance is due to dominant allele present on X chromosome, so this type of inheritance equally affects in male and female. However, all female children of affected father will be affected but no male children of affected father will be affected. The affected mother may affect 100% children if this dominant allele is located on both X chromosomes but if this dominant allele is located only on one sex chromosome then chances of affected children will be 50%. The examples of X-linked dominant inheritance are **hypophosphatemia** (rickets), **incontinentia pigmenti**, *etc.*

Y-Linked Inheritance

The inheritance of genes located on 'Y' chromosome. Since only male have 'Y' chromosome. Therefore some 'Y' linked genes can only be transmitted from father to son. The Y-linked inheritance is also called **holandric inheritance**. The concepts of dominant

and recessive do not apply to Y-linked traits, as only one allele is ever present in any one (male) individual. 'Y' linked inheritance never occur in females. The examples of Y-linked trait in male are **hypertrichosis** (growth of hair on ear pinna), **porcupine man** (straight hair on body) and **webbing of toes**, *etc.* (Fig.22.19)

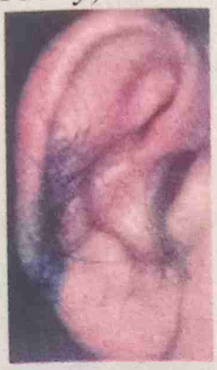


Fig.22.19: Hairy Pinna (Example of Y-linked Inheritance)

Extra Information

Recently two more genes located on Y chromosomes have been discovered.

i) Testis determining factor (TDF).

ii) Minor Histocompatibility gene (H-Y)

22.8.3 Sex Linked Disorders in Human

Sex linked disease are passed down in families through one of the X or Y chromosomes. Some sex linked disorders will be discussed here:

Genetics of Haemophilia

It is a serious disease of human in which blood fails to clot after it starts flowing from an injury site of haemophilia patient. It is an X-linked recessive trait *i.e.* its recessive allele is located on 'X' chromosome, say X^h. Its dominant allele says X^H favors blood clotting. It is very rare in females as female requires allele from her both father and mother which is very rare, as very few diseased males survive to marry and reproduce. On the other hand, male can easily get this disease, as they only need to get a recessive gene form the mother.

History of Haemophilia

The haemophilia is called royal disease because haemophilia gene was passed from Queen Victoria, who became Queen of England in 1837 to ruling families of Russia, Spain and Germany. Queen Victoria's gene of haemophilia was caused by spontaneous mutation.

There are three types of haemophilia *i.e.* haemophilia A, B and C. The allele for haemophilia A and B are located on X chromosome, so these two types are X linked. The allele for haemophilia C is located on autosome, so its chances are equal in male and female. However, haemophilia A and B are more common. Haemophilia A is caused due to missing blood clotting factor VIII and is about 80% of total haemophiliac patients. Haemophilia B is due to absence of blood clotting factor IX and it is about 20%. haemophilia C is due to missing of blood clotting factor XI and it is very rare (less than 1%).

Table 22.7: Comparison between different Types of Haemophilia

A	B	C
It is most common type.	It is 2nd most common type.	It is least common.
It is very severe.	It is moderate.	It is mild.
It is caused by missing of blood clotting factor VIII.	It is caused by blood clotting factor IX.	It is caused by blood clotting factor XI.

Genetics of Color Blindness

Color blindness is not a form of blindness at all, but a difficulty in distinguishing certain colors, such as blue, yellow, red and green. The color blindness is infact a color vision deficiency. It is X-linked recessive inheritance, therefore, more common in males than females. There are three fundamental colors. *i.e.* Red, green and blue. There are two types of photoreceptor cells in retina of eye *i.e.* Rod and cone cells. The rod cells are more abundant but these are incapable of perceiving color. The cone cells are responsible for color vision. There are three types of cone cells *i.e.* red, green and blue color receiving. The cone cells can receive these colors if they have opsin proteins. The three type of opsin protein is coded by different genes. The gene for red and green opsin are on X chromosomes while gene for blue opsin is on chromosome No.7 which is autosomal chromosome, so equally expressed in male and female. The color blindness may be in the form of dichromacy and monochromacy.

Extra Information

Some women can have a genetic mutation that makes them **tetra chromatic**, which causes their eyes to have 4 different types of cone cells enabling them to see 1000 million different colors as compared to a normal person who can see 100 million.

Dichromacy

A color blind patient with dichromacy can perceive two primary colors but unable to one primary color so dichromacy can further have three sub types

1) **Protanopia** is red color blindness.
2) **Deuteronopia** is green color blindness.
3) **Tritanopia** is blue color blindness.

Monochromacy

It is severe type of color blindness in which patient perceive only one color. It is true color blindness. Usually monochromate cannot perceive red and green colors. It's pattern of inheritance is same as other X-linked recessive inheritance like haemophilia. (Fig.22.20)

Introduction

The central idea of Biological evolution is that all life on earth share a common ancestor. Evolution can be defined as **descent with modification**, a phrase Darwin used in proposing that earth's many species and descendants of ancestral species that were different from present day species. **Evolution** can also be defined more narrowly as a change in the genetic composition of a population from generation to generation.

A brief description of main theories concerning the origin of life is presented in this chapter. Some evidences in support of evolution have also been provided. The Hardy-Weinberg principle and factor that change the allelic frequencies will also be discussed.

24.1 The Evolution of the Concept of Evolution

Understanding evolution is critical for understanding biology. Evolution is the only scientific explanation for **diversity of life**. It explains similarities among vast variety of life. There are many concepts about evolution. Two major and contradictory concepts of evolutionary thoughts are:

a) Special Creation b) Theory of evolution

24.1.1 Concept of Special Creation

The belief that the origin and diversity of life result from super natural event at a particular time in the past, whereby each species was created separately (from the act of God) is called special creation. The supporter of special creation is called **creationists**. This theory is supported by most of the world's major religions and civilizations. This concept is based on the references of Holy books. According to their interpretations that Allah has created everything in the universe in **six days** and human was created at sixth day. In fact, the **faith** accepts things for which there is no evidence in the scientific sense. This means that logically there can be no intellectual conflict between scientific and theological account of creation, since they are mutually exclusive **realms of thoughts**. In most cases the **scientific truth** to the scientists is **tentative**, but **theological truth** to the believer is **absolute**.

Evolution rarely follow a straight line from species to species. Instead it is more like a tree with many bran-ches. Some branches lead to new branches, while other become dead ends.

24.1.2 Concept of Evolution

In biology, evolution is the change in the characteristics of a species over several generations and theory of evolution is based on the idea that all species are related and change over time. The supporters of evolution are called **evolutionists**. According to

their point of view, universe and man did not always exist in their present form but result of many changes from lower to higher order. They also reject the theory of special creation. According to **big bang theory** the life began on earth about **3.5 billion** years ago. The fossil record supports this hypothesis that life originated from simple **prokaryotic organism** and then **eukaryotic organisms** developed from this prokaryote about **1.9 – 2.1 billion** years ago. The present day biodiversity is the result of these continuous evolutionary changes. The concept of evolution did not begin by Darwin and publication of his book "Origin of Species". The evolutionary concepts were present at the time of **Aristotle** about (384-322BC).

24.1.3 The Process of the Evolution of Man in the Holy Quran

The Quran is clear in its support that humans came from lower beings and that creation had a process involving diverse successive stages.

Allah Almighty started the creation of life on Earth, and then left it to evolve as a result of learning from the adaptation to various environments, which intervention from Him to make His creation better. As far as origin of man is concerned.

Allah Says in Quran "O mankind! Be careful of your duty to your Lord Who created you from a single soul and from it created its mate and from them has spread a multitude of men and women". *(Surah Nisa, Verse-1)*

This verse tells us that the beginning of life was a single soul, then its mate came out of it. Biological science tells us that the earliest form of life was represented by single cell organisms found in water, then these multiplied by splitting themselves. With the course of time, reproduction started to be by mating pairs, instead of the archaic forms of splitting or dividing.

Allah Says in Quran "Allah is He) who has made everything He created better and He began the creation of the human (being) out of clay". *(Surah Sajda, Verse-7)*

In this verse, we are told that Allah (Praise to Him) began the creation of human beings out of clay, but that was the beginning, then He improved His creation making it better.

The most relevant word in this verse is "**began**" (bada-a), which tells us clearly that creation happened in a process that had a beginning, not just at once.

Allah Says in Quran "He has created you in diverse (and successive) stages". *(Surah Nooh, Verse-14)*

This verse may be interpreted to refer to the successive stages of the development of a foetus in its mother's womb. However, it can also be interpreted to refer to the successive stages of the human evolution.

Allah Says in Quran "We created the human being from stinking, smooth, and wet

clay". *(Surah Al-Hajar, Verse-28)*

This verse gives a very specific description of the environment where life started. It refers to swamps where still water in combined with the earth soil, which creates stinking but smooth clay easy to take different forms.

.This is exactly what biologists have come up with to explain the beginning of life on Earth.

Allah Says in Quran "It is He Who created you, fashioned you perfectly, and made you with the right proportions (straightened you up, to walk in an upright position". *(Surah Infitar, Verse-7)*

This verse may refer to three main stages of the creation of human beings. The first was creation of a living cell (The Arabic verb Khlaqa, created). The second was the change from unicellular prokaryote organism to the multi-cellular eukaryote organism (the Arabic verb sawwa, fashioned you perfectly). The third was the human departure from the animal stage (The Arabic verb 'adala' made you walk in an upright way).

Allah Says in Quran "Roam the earth and observe how the creation was initiated". *(Surah Ankabut, Verse-20)*

This verse is a direct commandment to humans telling us to travel the earth and observe how creation was brought forth. Interesting thing is that Darwin followed this verse unknowingly and discovered how creation formed.

24.1.4 Origin of Life According to Concept of Evolution

The **vent hypothesis** suggests that life may have begun at **submarine hydrothermal vents**. The first sea **hydrothermal vent** was discovered in 1977 in Pacific Ocean. The fossil found in these vents are about 3.5 billion years old. These fossils belong to a group of prokaryotes, *e.g.* the archaeobacteria (now called archea). It is also believed that the early atmosphere of earth was oxygen free, hot and ozone less. Therefore, frequent exposure of ultra violet radiation was there. This primitive earth's atmosphere has very little nutrients and first prokaryotes were **absorptive heterotrophs**. Later chemoautotrophs were evolved. The **photosynthetic organism** evolved about 3.2 billion years ago. This first photosynthetic organism used hydrogen sulphide as source of hydrogen for sugar molecule instead of water. These prokaryotes still use hydrogen sulphide (H_2S) as source of hydrogen for carbohydrate and produce sulphur (S) as by-product. Later on when cyanobacteria evolved, these started using H_2O as source

Focus Concept of Evolution

The theory of evolution states that species change over time. The primary mechanism for this change is natural selection. The fossil record, morphology, biogeography, comparative anatomy, embryology and molecular biology all provide evidences for evolution.

of hydrogen in synthesizing carbohydrates and liberated O_2 as a by-product. This O_2 accumulated in atmosphere. Thus slowly and gradually **ozone layer** formed. This ozone layer acts as filter for ultraviolet radiations from the sun. When eukaryotic photosynthetic organism evolved about 1.9 – 2.1 billion years ago, the production of O_2 increased many folds and ozone layer got thicker and more protective for life on land. This increased the biodiversity on earth.

24.2 Evidences of Evolution

The evidences to support theory of evolution is provided by many sources. Some important evidences are discussed here.

i) Evidence from Biogeography

The study of the geographical distribution of fossils and living organisms is called biogeography. A comparison of recently formed fossil types of living organisms in the same geographic area shows that new organisms arise in area where similar forms already lived. Thus, **armadillos** appeared in North and South America where **glyptodonts**, lived in the past. Modern kangaroos appeared only in Australia, which evolved from extinct giant kangaroo. Darwin found 13 species of finches in Galapagos Islands, which are not found anywhere else in the world, as far as he knew. He concluded that the finches had evolved from a common ancestral group that probably reached the island many generations earlier. In the isolation of the **Galapagos island**, the original finches had probably evolved into the 13 species.

The study of biogeography supports the theory of evolution as it is found that closely related species are usually found in close physical proximity to one another. The fossils from these regions resemble modern organisms. This suggests that these species share a common lineage.

Age of Earth

The most recent estimate of the age of the earth was published in the journal nature in August, 2005. The age of the earth as estimated from the age of meteorite is 4569 million years old.

ii) Evidence from Palaeontology

The study of past life with the help of fossils is called palaeontology. The study of forms of life existing in prehistoric or geologic times, as represented by the fossils (Lt = fosilium = something dug up) of plants, animals and other organisms.

Palaeontology supports the study of evolution because it shows a descent of modern organisms from common ancestors. Palaeontology indicates that fewer kinds of organisms existed in past eras, and organisms were probably less complex. **Palaeontologists** descend deeper and deeper into layers of rock, the variety and complexity of fossils decrease. The fossils from the upper most rock layers are most like current forms. The oldest known fossils are of prokaryotes. Therefore, prokaryotes are

considered as ancestors of all life forms on earth. The fossil record may allow us to trace the history of one particular organism, *e.g.* the fossil record of different genera and species of horses indicate that **earliest horses** had four toes. Then after a long period of time, the number of toes reduced to three. In modern day horses, the large central toe is present which ends in a hoof. Thus paleontology supports the theory of evolution. (Fig.24.1)

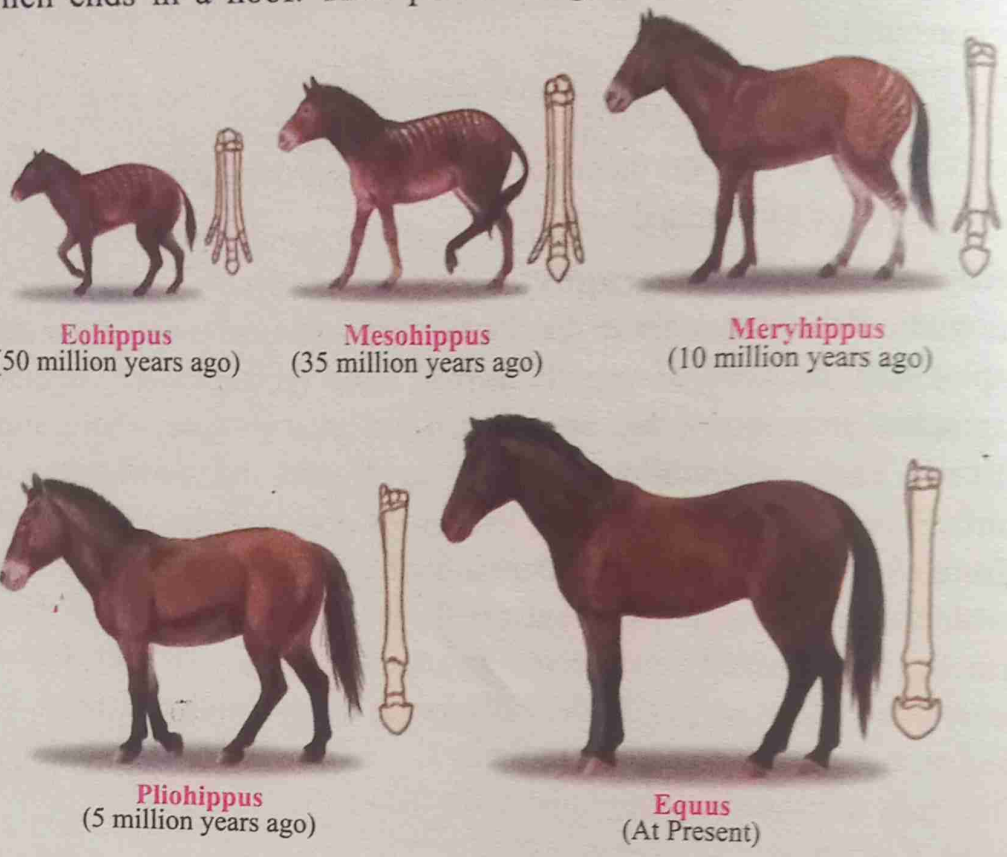


Fig. 24.1: Evolution of Horse

iii) Evidence from Comparative Anatomy

Anatomy is a field of biological sciences which is concerned with the identification and description of the internal body structures of living things.

The study of comparative anatomy predates the modern study of evolution. Early scientists like **Buffon and Lamarck** used comparative anatomy to determine relationship between species. They believed that organisms with similar structures have originated from common ancestor. Today, comparative anatomy can serve as the first line of reasoning in determining the relatedness of species. However, there are many hidden dangers that make it necessary to support evidence from comparative anatomy with evidence from other fields of study.

Homologous and Analogous Structures

Homologous are those structures which are similar in structure but may or may not have the same functions *e.g.* the forelimbs of different mammals like human, cat,

whale and bat have same basic pattern of bones: However, their fore limbs have different function. This indicates that these mammals have common ancestor. (Fig.24.2)

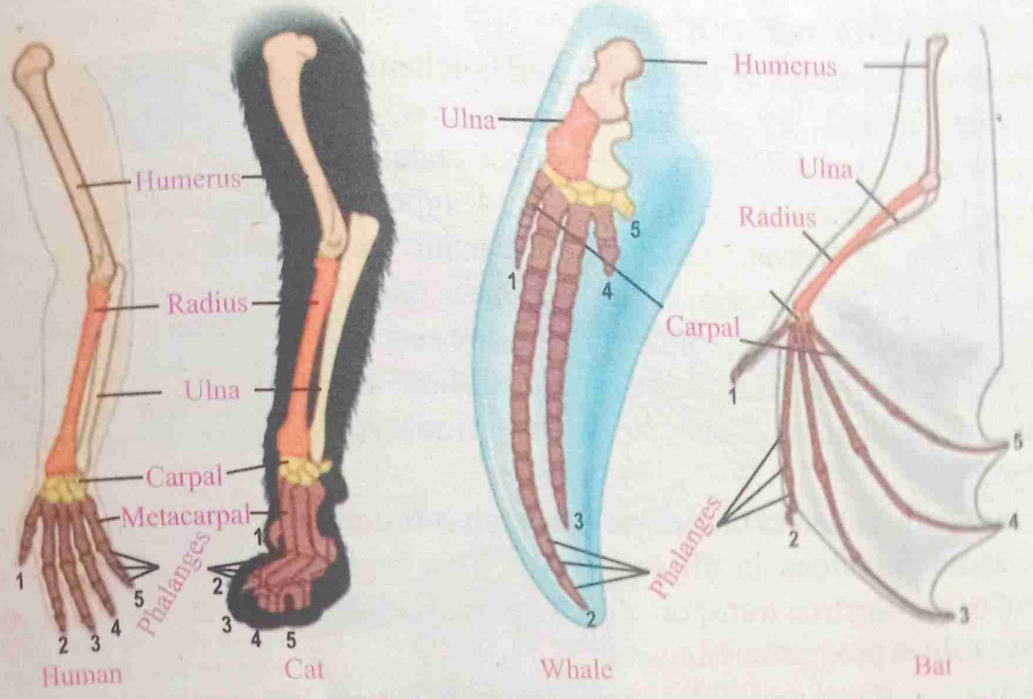


Fig. 24.2: The fore limbs of Human, Cat, Whale and Bat showing Homologous Structure

The homologues struct-ure shows **divergent evolution**.

Analogous structures are those structure which are different in structure but similar in function. These structures perform similar function but may be different in their basic pattern *e.g.* the wings of bats and birds look similar from outside. They also have the same function. However, wing evolved independently in two groups of animals.

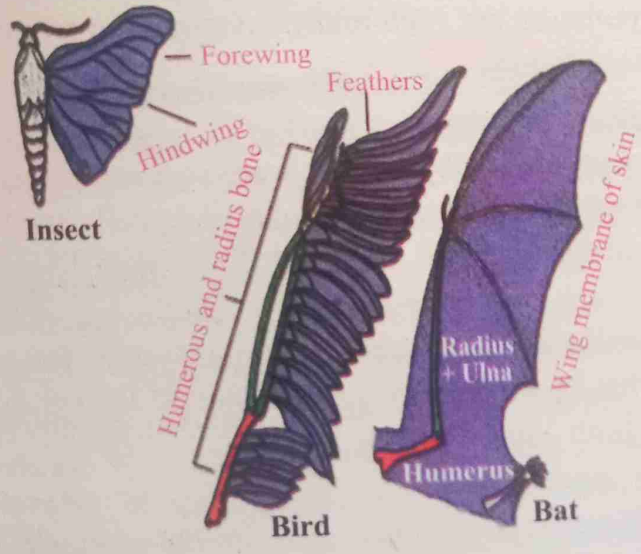


Fig. 24.3: Analogous Structure of Birds, Bat, Insects

Extra Information

Some snakes have hipbones, which show they once had four legs like lizards, their close cousins.

Moreover, the bird wings and insect wings are also analogous traits. This type of evolution is called **convergent evolution**. (Fig. 24.3)

Evidence from Molecular Biology

There are certain key molecules and biochemical mechanisms shared by different organisms. All organisms use DNA and RNA for their genetic code. The DNA in all organisms is composed of 4 types of nucleotides *i.e.* Adenine, Guanine, Cytosine and Thymine. The ATP molecule is the common energy currency in all organisms. The process of photosynthesis, cellular respiration, transcription and translation are all identical or very similar in various type of organisms.

Extra Information

Inside some whales and dolphins are small limb bones which show that once had back legs and that their ancestors walked on land. These occasion-ally reappear as tiny rear flippers.

A molecule called **cytochrome C**, which is found in all organisms. This molecule performs same functions in all organisms. This highly conserved protein is a key component of the electron transport chain (a part of cellular respiration). The cytochrome C also plays role in programmed cell death.

Similarity, these molecules make sense that these are important molecules and therefore, present in most of organisms. However, it would not make sense if each of these molecules appeared independently in each species. These shared biochemical molecules and pathways provide strong evidence for common descent and evolution.

24.3 Evolution of Eukaryote from Prokaryotes

Fossil records indicate that eukaryotes evolved from prokaryotes somewhere, between 1.9 - 2.1 billion years ago. Two hypothesis have been proposed to describe the evolution of eukaryotes. These hypotheses are membrane invagination hypothesis or theory and endosymbiotic hypothesis or theory.

24.3.1 Membrane Invagination Theory

The invasions of the host prokaryotes cell probably were successful because the host cell membrane infolded to surround both invading prokaryotic cells and there by transport them into the cell. The membrane did not dissolve but remained intact, and there by created a second membrane around the **promitochondria** and **prochloroplast.** It is also known that in modern day eukaryotes the inner membrane of both mitochondria and chloroplast contain structures more similar to prokaryotes than eukaryotes. Whereas the outer membrane retains eukaryote characteristics. It is also

Extra Information

You might think that you are special, but believe it or not you share about 50% of your DNA with a banana and approximately 31% of your genes with yeast, which is a single celled organism.

suggested that continued membrane infolding created the endomembrane system. It can be said that possibly the first eukaryotic cell type was born from prokaryotic, symbiotic, multi cell interactions. (Fig.24.4)

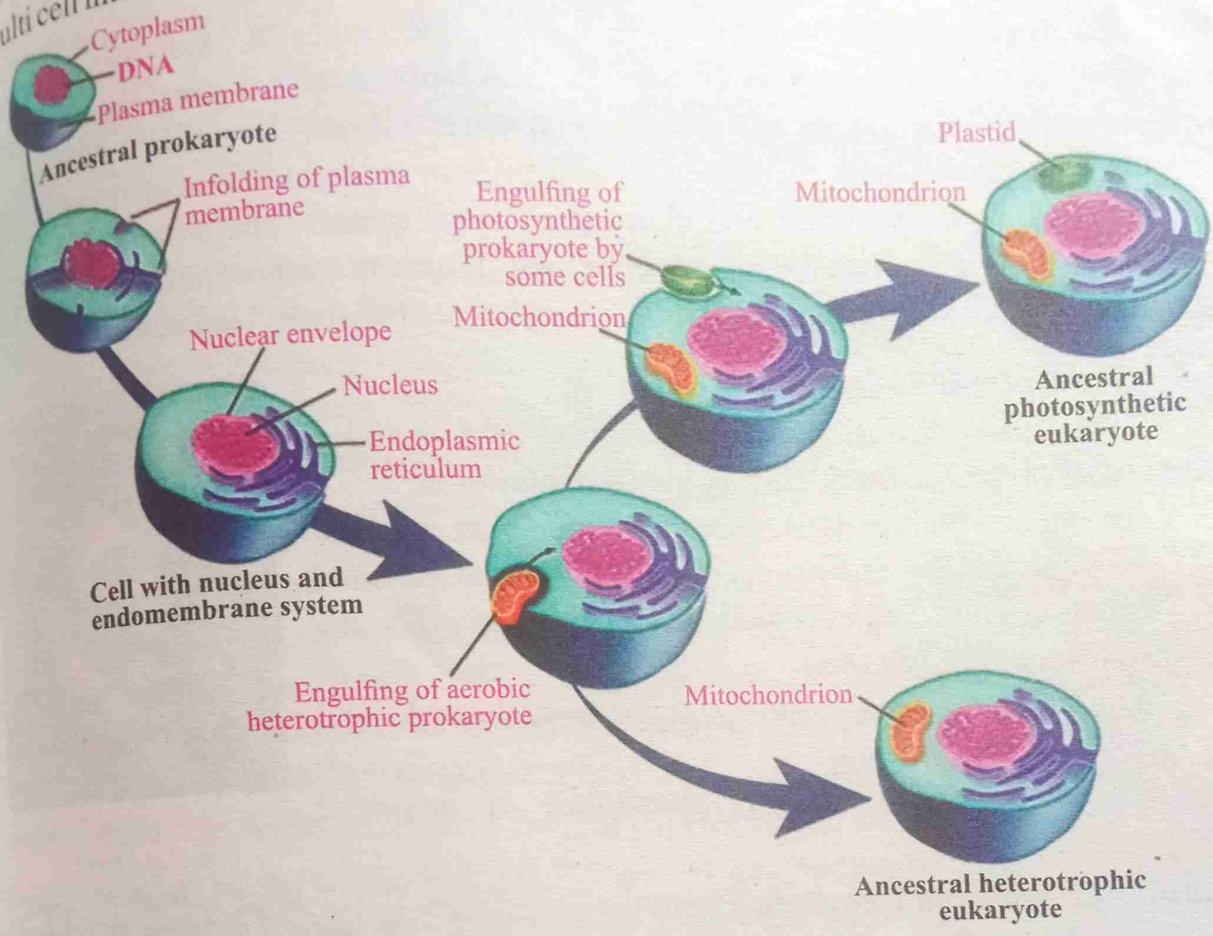


Fig. 24.4: Endosymbiotic Theory and Cell Invagination Theory

24.3.2 Endosymbiosis Theory

Research conducted by **Lynn Margulis** supports the hypothesis that two separate mutually beneficial invasions of a prokaryote cell produced the modern day mitochondria and chloroplast as eukaryotic organelles. In this model, ancestral mitochondria were small heterotrophs capable of using oxygen to perform cellular respiration and thereby create useful energy. They become part of a large cell either by direct invasion as an internal parasite or as an indigestible food source. Later a second invasion brought ancestral chloroplasts, which are thought to be small photosynthetic cyanobacteria. Modern day supporting evidence for endosymbiosis shows that both mitochondria and chloroplasts have their own genes,

Interesting Information

Monkey is different from ape. Monkeys have tails and narrow chest. Apes are tailless and have broad chests.

circular DNA and RNA, and reproduced by binary fission independent of the host's cell cycle. They therefore, appear to be more similar to prokaryotes than eukaryotes.

24.4 Lamarckism

Jean Baptiste de La Marck (August 1, 1744 – December 28, 1829) was a **French naturalist** and early proponent of idea that evolution (descent with modification) occurred and proceeded in accordance with natural laws. Lamarck, however, is remembered today mainly in connection with his now rejected theory of heredity, the inheritance of acquired traits. Lamarck is regarded as a premier authority of plants and invertebrate zoology and well known **toponymist** (Expert of study of places names). He also wrote a book **Philosophie Zoologique** (Zoological Philosophy) in 1809.

24.4.1 Lamarck's theory of Evolution

The theory about evolution presented by Lamarck is called Lamarckism. Lamarck's theory involved two ideas.

i) An organ which is used more and more by an organism becomes bigger and stronger, and one that is not used, becomes weak and eventually disappears. He called this concept use and disuse.

ii) Any feature of an organism that is improved through use is passed to its offsprings.

This concept was called **inheritance of acquired characters.** (Fig.24.5)

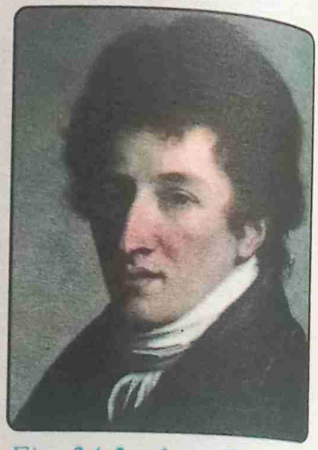


Fig. 24.5: Jean Baptiste de La Marck

Examples to Support Lamarck Theory

Evolution of Giraffe

According to Lamarck, the ancestors of giraffe looked like horses with small neck and forelimbs. They lived in areas where there was no surface vegetation. Therefore, they had to stretch their neck and forelimbs to eat leaves from tall plants. Consequently, these parts got elongated. This trait was transmitted in the succe-ssive generations. (Fig.24.6)

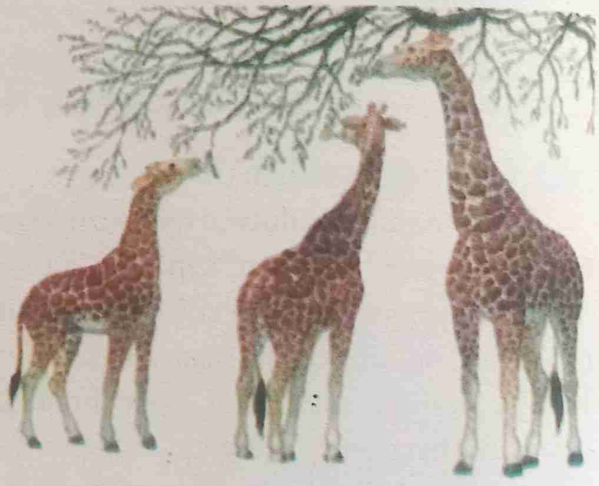


Fig. 24.6: Evolution of Giraffe Neck

Extinction of Limbs in Snakes

The snakes are believed to have evolved from lizard like ancestors that had two pairs of limbs. Due to disuse of the limbs, the limbs got weaker and shorter and eventually disappeared.

Flightless Birds

It is believed that the ancestors of birds such as Ostrich were able to fly. Due to some environmental changes, they had a lot of food and well protected. They did not use wings and as a result the wings became **vestigial**.

24.4.2 Drawbacks of Lamarckism

Lamarck's theory of acquired characters couldn't gain popularity and acceptance due to following drawbacks.

i) There is no experimental proof of his theory.
ii) New organs are not formed in organisms by requirement.
iii) It is not necessary that the acquired character transmits into new generation.

Moreover, a German biologist **August Weisman,** in 1880s disproved the Lamarck's theory of inheritance by giving experimental proof. He removed tails of 68 mice, repeatedly for many generations, and reported that no mice were born without a tail or even with shorter tail. This rejects the theory of inheritance of acquired characters.

24.5 Darwinism

Charles Darwin was born on February 12, 1809 in **Shrewsbury,** England and died at **"Down House"** in Kent on April 19, 1882. He is known as father of evolution. He was selected as naturalist on **HMS Beagle** (A British naval ship about to sail around the world to expand the navy's knowledge of natural resources). He wrote the book **"Origin of species by means of natural selection".** In his book, he has given the idea of evolution by means of natural selection. (Fig.24.7)

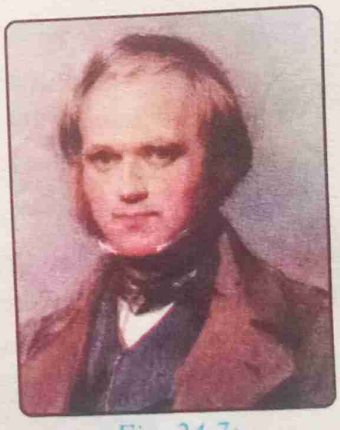


Fig. 24.7: Charles Darwin

24.5.1 Darwin's Observations During his Voyage

In 1831, when Darwin was just 22 years old, he set sail on scientific expedition on a ship called the HMS Beagle. He was the naturalist on the voyage. As a naturalist, it was his job to observe and collect the specimens of plants, animals, rocks and fossils wherever the expedition went ashore. During this long journey Darwin made observations.

Darwin Finches

One of the most famous species that Darwin observed were finches that lived on Galapagos Islands. He found 13 different species of finches and noted the main differences amongst the finches on each island which were their beak shape. He observed that finches on each island had beak shapes that were applicable for the type of food that was available on the island. (Fig.24.8)

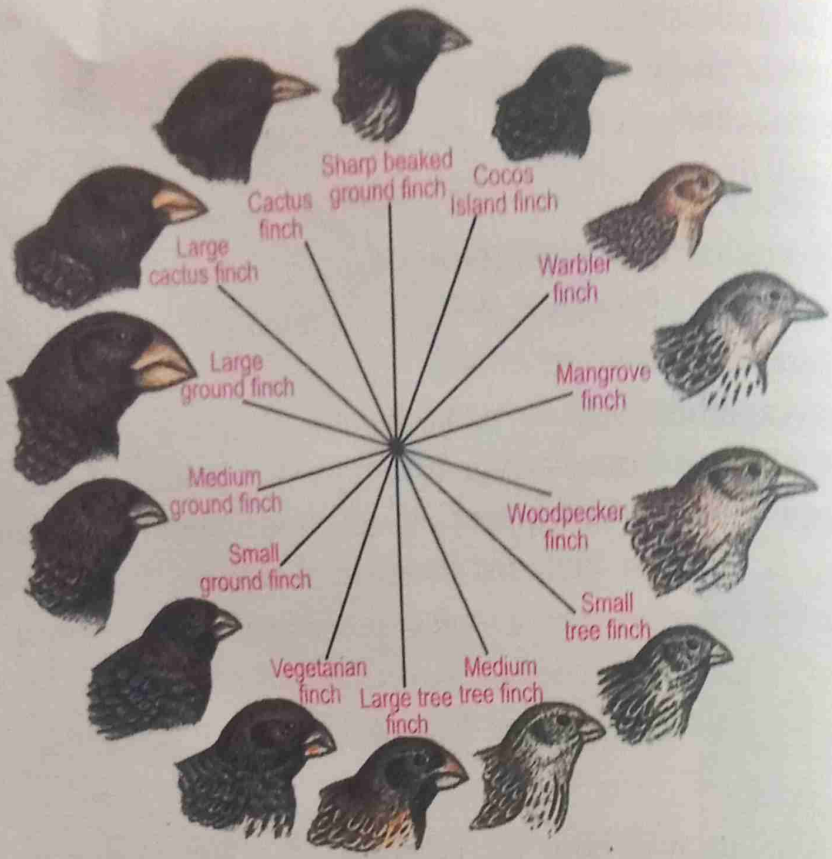
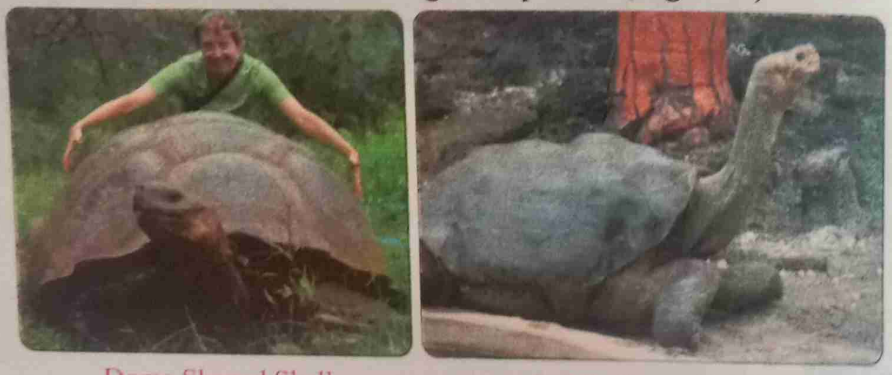


Fig. 24.8: Darwin Finches of Galapagos Island

Giant Tortoise

Darwin also observed giant tortoises in Galapagos Islands. The **Galapagos Islands** were named for their giant tortoises. Darwin noticed that tortoise on one island had **saddle-shaped shell**, while those on another island had **dome shaped shell**. This observation made Darwin to think about origin of species. (Fig.24.9)



Dome Shaped Shell Saddle Shaped Shell

Fig. 24.9: Tortoises of Galapagos

Fossils of South America

In South America, Darwin found fossils that resembled modern animals however, they had differences is size and adaptations. It made him realize that living things had ancestors and that species change over time.

4.5.2 Development of the theory of Evolution

Although Darwin presented his theory of **natural selection** in 1859 in his famous book "origin of species" but he started his work in 1836 after return from 5 years trip of HMS Beagle. In the meanwhile, he collected the data to support his idea. His theory of evolution is not only based on his observations, but he was also inspired by the work of many other scientists of his time. Therefore, he also shared the ideas of these scientists in the development of his theory.

Contribution of Charles Lyell

He was well known English **geologist**. He wrote a book **"Principles of Geology"**, in his book Lyell argued that gradual geological processes have gradually shaped Earth's surface. Darwin was impressed and he took his book with him on the Beagle voyage.

Extra Information

The size of Galapagos tortoise is about 4 feet, weight 475 pounds, average life span is 100 years and it feeds on plants.

James Hutton (1726 - 1797)

He was Scottish geologist, chemist and naturalist. He has given the concept of **uniformitarianism**, which explains the features of the earth's crust by means of natural processes over geological time. He was also the first person to propose a mechanism of natural selection to account for evolutionary change over time. Darwin was also inspired by Hutton's work.

Thomas R. Malthus (1766 – 1834)

He was an English **economist**. He wrote an **essay on population**. In the essay, he argued that human populations grow faster than the resources they depend on. When populations become too large, famine and disease breakout. In the end, this keeps populations in check by killing off the weakest members. Darwin read the article during his journey and influenced by his thoughts.

Alfred Russell Wallace (1823 – 1913)

Wallace lived at about the same time as Darwin. He also travelled to different places to study nature. However, he developed basically the same theory of evolution while working on distant lands, Wallace sent Darwin a paper he had written. In the paper, Wallace explained his evolutionary theory. This served to confirm what Darwin already thought.

Interesting Information

The phrase "survival of the fittest" associated with Darwin was coined by biologist Herbert Spencer after reading Darwin's work.

Why the theory was attributed to Darwin?

Although the Wallace developed basically the same theory of evolution as described by Darwin. Moreover, Hutton was the first person to propose a mechanism of

natural selection. The Alfred Russell Wallace also motivated Darwin to publish his book about the origin of species by means of natural selection. However, Darwin came up with great supporting evidences from a wide variety of scientific disciplines, including palaeontology, geology, vestigial organ, biogeography and comparative anatomy. Darwin spent more than 30 years in studying and observing nature before concluding his ideas. Therefore, this theory was attributed to Darwin.

Extra Information

At the time of Darwin's death in 1882 his book had been published. The origin of species has been translated into 29 languages including Turkish, Hindi *etc.*

24.5.3 Darwin's Theory of Natural Selection

According to this theory various types of plants, animals and other living things on earth have their origin in other pre-existing types and that the distinguishable differences are due to modifications in successive generations. There are two main points of Darwin's theory of evolution *i.e.*

- Descent with modification
- Natural selection.

Descent with Modification

Descent with modification means passing on the traits from parent organism to their offsprings. According to Charles Darwin, all species descended from only a few life forms that had been modified over time. This descent with modification as he called it, forms the backbone of his theory of evolution.

Natural Selection

Natural selection is the process in nature by which organisms better adapted to their environment tend to survive and reproduce more than those less adapted to their environment. There are four observations about natural selection.

a) Over Production

Each species has the capacity to produce more offsprings that can possibly obtain food and survival. If all offsprings of any species remained alive and reproduce, they will soon over crowd the earth and could destroy all other species. For example if each breeding pair of elephants produces six offspring during its 90 year life span, in 750 years a single pair of elephants will give rise to a population of 19 million. Yet elephants have not overrun the planet.

b) Struggle for Existence

The individuals increase enormously in number but the space and food available remain almost constant. There is always an active competition and three- fold struggle to ensure living, to obtain the maximum amount of food and better place. The struggle for

existence may be:

1. **Intra Specific:** Competition among the organisms of same species.
2. **Inter Specific:** Competition among the organisms of different species living together.
3. **Environmental Struggle:** Struggle against various environmental conditions.

c) **Variations**

The individuals in a population exhibit variation in their traits. Some of these traits improve the chances of an individual's survival and reproductive success, whereas other traits do not. Variation necessary for evolution by natural selection must be heritable.

d) **Survival of the fittest**

As a result of competition among the organisms, the stronger win and survive (variant) while the weaker less variant are rooted out. *e.g.* if there is flood only those organisms that can swim or respire in water, have a better chance to survive and other will die. Darwin called it natural selection. It is also called survival of the fittest.

The process of natural selection thus causes an increase in favorable alleles and decrease in unfavorable alleles with in the population. Over succeeding generations, individual members become better adapted to local, conditions, thus leading to the evolution of new species.

24.6 Neo-Darwinism

Neo-Darwinism also called the **modern evolutionary synthesis**, generally denotes the integration of Charles Darwin's theory of evolution by natural selection, Gregor Mendel's theory of genetics as a basis of biological inheritance, and mathematical population genetics. **Neo-Darwinism** has been one of the most significant, overall developments in evolutionary biology, since the time of Darwin, Neo-Darwinism introduced the connection between two important discoveries: the unit of evolution (gene) with the mechanism of evolution (natural selection).

24.6.1 Hardy-Weinberg Theorem

Godfrey Hardy and **Wilhelm Weinberg** developed relationship between the frequencies of alleles and genotypes in 1908. They pointed out that the frequencies of various genotypes in a population can be described mathematically which is known as Hardy-Weinberg principle; it states that "Both the ratios of genotypes and frequency of alleles remain constant from generation to generation in a sexually reproducing population provided other conditions are stable".

Conditions/assumptions for stability

Hardy-Weinberg principle describes how a population can remain at genetic

equilibrium. **Genetic equilibrium** occurs when there is no evolution within the population. At genetic equilibrium, the gene or allele frequencies are stable. They do not change. There are following conditions that must be met for genetic equilibrium to occur:

1. No mutation (change) in DNA sequence.
2. No migration (moving into or out of a population).
3. Random mating.
4. No natural selection.

These conditions rarely occur in nature. If one or more of the above conditions do not exist, then evolution can occur. As a result, allele frequencies are constantly changing, and populations are constantly evolving.

Problem of Gene Frequency

The allele for grey body B is dominant to black body color b. There are 30% recessive alleles in the gene pool having population of 1000 individuals. Calculate the number of grey body individuals and black body individuals in a population.

Factors that change allele frequencies

There are number of factors which may lead to change in allele frequencies. These factors include.

a) Mutation: It is the change in genome of an organism. It is major source of variations and natural selection.

b) Migration or gene flow: It is the movement of individuals from one population to another. If a foreign individual migrates (comes) into the population is called **emigration**. If an individual migrates (goes out) of the population is called **immigration**. In both cases, allele frequencies will change accordingly.

c) Non-random mating: It is the mating among specific group of individuals in a large population. Individuals will mate more frequently with close individuals than more distant ones. Although new alleles cannot be developed by non-random mating but it can cause an increase in homozygous genotypes.

d) Natural Selection: Populations vary in the type of individuals and their reproductive success. Those individuals who leave more offsprings behind than others, pass on more of their alleles and have a better success rate in dominating the population. The selection may be artificial in which breeder select for the desirable traits.

Hardy-Weinberg Equation

It is not only important in population genetics; public health scientists also use it to estimate the percentage of people carrying alleles for certain diseases. Estimating the frequency of harmful allele is useful for the public health programs dealing with genetic diseases.

Hardy-Weinberg Equation

It is a mathematical equation that can be used to calculate the genetic variation of a population at equilibrium. This equation is an expression of the principle known as

Hardy-Weinberg equilibrium, which states that the amount of genetic variation in a population will remain constant from one generation to the next in the absence of disturbing factors *e.g.* mutation genetic drift etc.

To explore Hardy Weinberg equation, we can examine a simple genetic locus at which there are two alleles, 'A' and 'a'. The Hardy-Weinberg equation is expressed as $p^2 + 2pq + q^2 = 1$ where 'p' is frequency of 'A' allele and 'q' is the frequency of the 'a' allele in the population. In the equation 'p^2' represents the frequency of the homozygous genotype 'AA', while 'q^2' represents the frequency of homozygous genotype 'aa' and '2pq' represents the frequency of heterozygous genotype 'Aa'. In addition, the sum of the allele frequencies for all the alleles at a locus must be '1', so $p + q = 1$. If the 'p' and 'q' allele frequencies are known, then the frequencies of the genotypes may be calculated using the Hardy-Weinberg equation. In population genetics studies, the Hardy-Weinberg equation can be used to measure whether the observed genotype frequencies in a population differ from the frequencies predicted by the equation. (Fig.24.10)

p = frequency of allele A in population
q = frequency of allele a in population
if there are only 2 alleles for a gene then:
p+q=1 or 100%
Allele frequencies can be used to
Determine genotype frequencies too!
$p^2+2pq+q^2=1$

Example: If there are 200 M alleles in the gene pool and 800 m alleles, the
0.2+0.8=1
M m
and $(0.2)^2+2(0.2\ \ 0.8)+(0.8)^2=1$ or 100%
MM Mm mm
0.04 0.32 0.64

The Hard-Weinberg equilibrium is never achieved in nature, but it's very useful in studying populations.

Fig. 24.10: Hardy Weinberg Equation

24.6.2 Genetic Drift

Genetic Drift is a change in allele frequency in a population due to a random selection of certain genes. Mostly mutation within the DNA can have no effect on the fitness of an organism. These changes in genetics can increase or decrease in a population simply due to chance.